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MAY 2023

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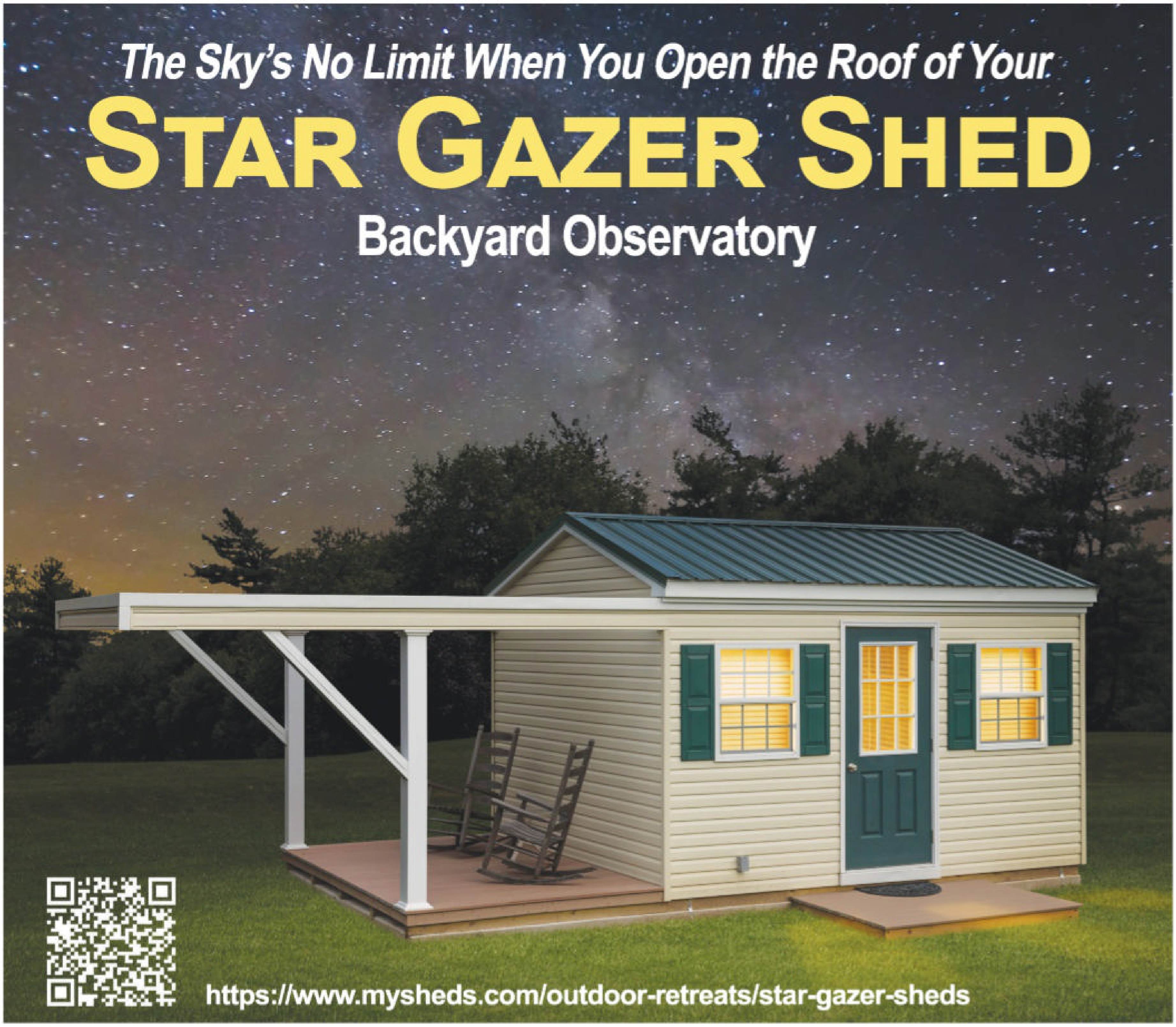

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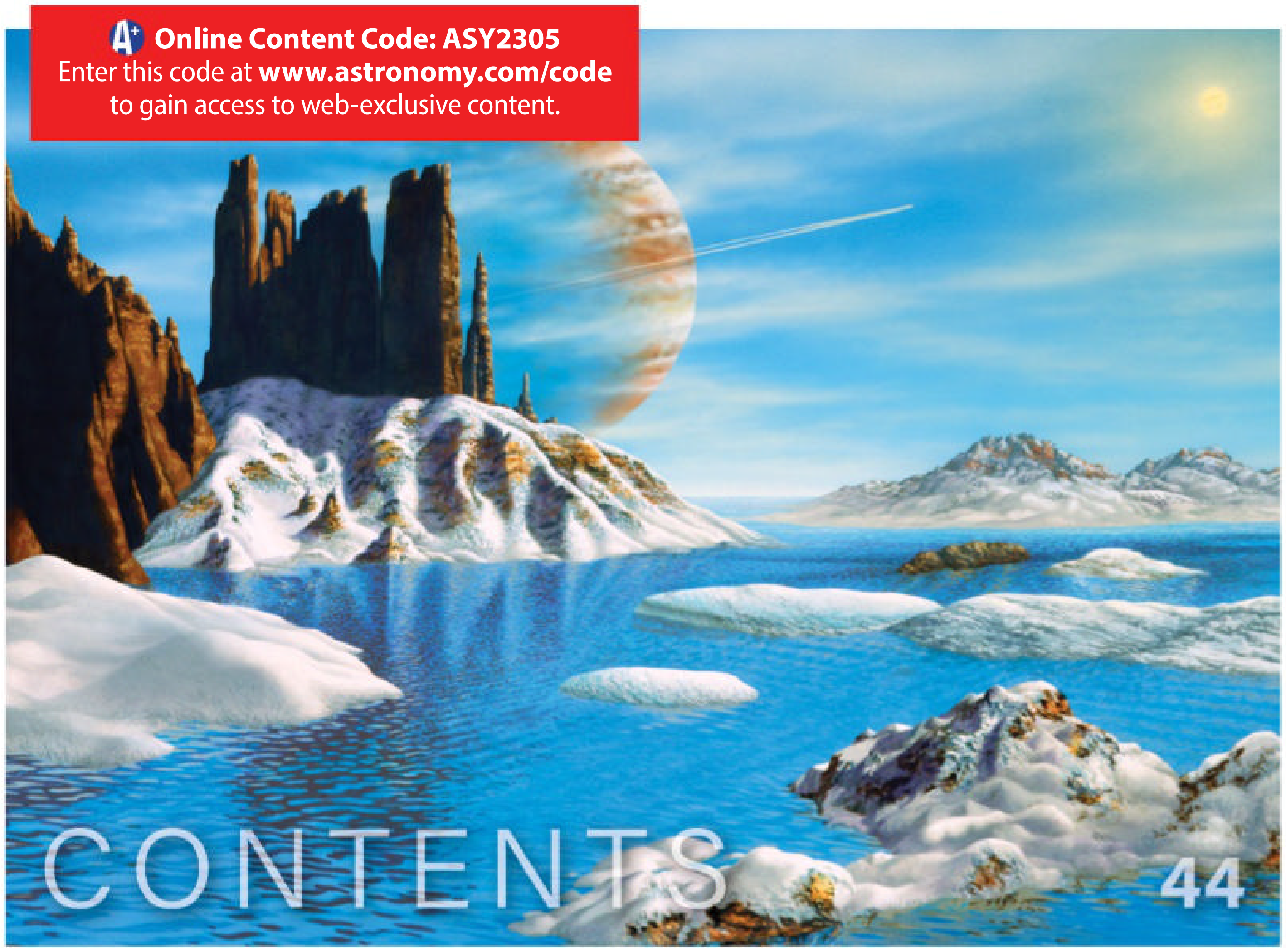

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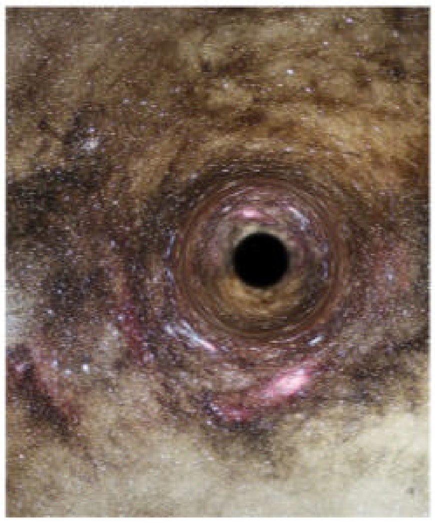

ON THE COVER

The Milky Way should host millions of stellar black holes. But we only know about a handful. Are there countless rogues? ESA/HUBBLE, DIGITIZED SKY SURVEY, NICK RISINGER (SKYSURVEY.ORG), N. BARTMANN

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Some 100 million isolated black holes lurk within the Milky Way. We're finally starting to bring them into the light. **ASHLEY BALZER VIGIL**

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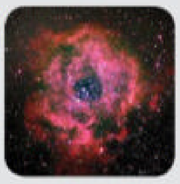

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Gorgeous photos from our readers.

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The latest updates from the science and the hobby.

Dave's Universe
The inside scoop from the editor.

My Science Shop
Perfect gifts for your favorite science geeks.

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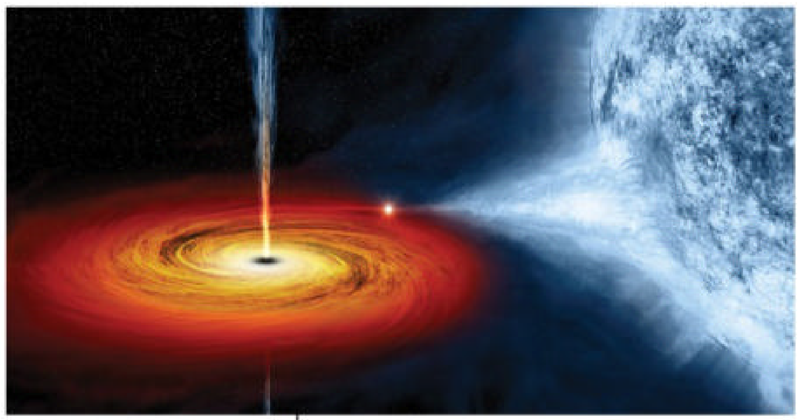
FROM THE EDITOR

Those ubiquitous black holes



The first confirmed black hole, Cygnus X-1, is shown drawing material from its companion star, HDE 226868, in this illustration. OPTICAL: DSS; ILLUSTRATION: NASA/CXC/M. WEISS

Black holes should be practically everywhere. In the Milky Way Galaxy, you shouldn't be able to go across the street without hitting one. Stellar mass black holes result from dying, massive stars, which end their lives in supernova explosions. So, given the stellar population history of our galaxy, there ought to be tens of millions or more black holes in the Milky Way. And yet we know of only about two dozen.

Why? They are very hard to detect. Black holes were hypothesized by the English natural philosopher John Michell, who calculated that collapsed "dark stars" with extreme gravity ought to exist. That was in 1783. Despite this, evidence for the first stellar black hole wasn't confirmed until 1990, with the famous "bet" between Stephen Hawking and Kip Thorne.

During the first years of the 1990s, astronomers using the Hubble Space Telescope began discovering many examples of supermassive black holes in the centers of galaxies. Now they know that most galaxies, with the exception of low-mass dwarfs, have central black holes. That includes our own Milky Way and its Sagittarius A* black hole.

But finding stellar mass black holes is still much harder. The handful we've found in the Milky Way are interacting with luminous objects, making their effects detectable. On page 14, science journalist Ashley Balzer Vigil delivers a story on so-called rogue black holes, the 100 million we haven't yet found in our galaxy. She aptly describes how astronomers are on the cusp of new discoveries, and new techniques, that will bring the population of the fascinating objects to a fuller cataloging.

I hope you'll enjoy the story of these mysterious objects that lie scattered throughout our cosmic neighborhood. And as you read about them, you can thank your lucky stars that not one is too close for comfort.

Yours truly,

David J. Eicher
Editor

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ASTRO LETTERS

Comet Mrkos (photographed here in 1957), is characterized as a great comet and had a magnitude of 1, brighter than Halley's Comet at its peak. DONN, BERTRAM; RAHE, JUERGEN; BRANDT, JOHN C. FROM *ATLAS OF DRAWINGS AND PHOTOGRAPHS OF COMETS*/WIKIMEDIA COMMONS

We welcome your comments at Astronomy Letters, P.O. Box 1612, Waukesha, WI 53187; or email to **letters@astronomy.com**. *Please include your name, city, state, and country. Letters may be edited for space and clarity.*

Memorable viewing

Your January 2023 issue was excellent! The bright comet list brought back pleasant memories of nights outdoors. I graduated from high school in 1957, and that is the only year I remember seeing two naked-eye comets: Comet Arend-Roland and Comet Mrkos (formally known as C/1957 P1). I recall hauling my small scope atop our high school building to watch them with members of our science club. Your notes about comet photography correctly point out how digital photos are now easy to take; it's too bad we only had a Kodak Hawkeye camera in 1957. —**Roger Grossenbacher,** Lancaster, OH

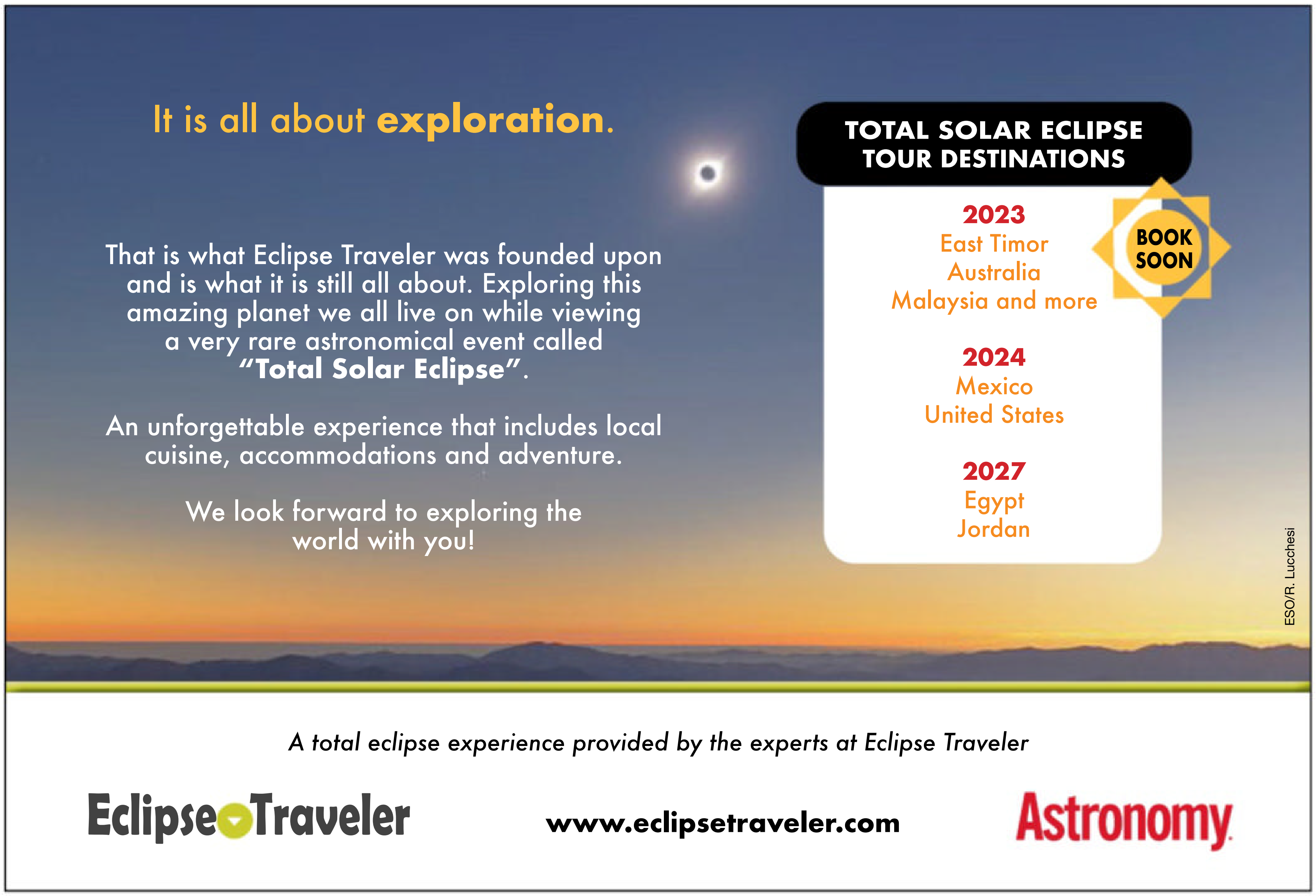
Missing mission

I am disappointed that your January 2023 special issue on comets failed to mention the historic Stardust mission, which brought back samples from the coma of Comet Wild-2 and then went on to visit Comet Tempel 1.

Launched Feb. 7, 1999, Stardust flew by asteroid 5535 Annefrank on Nov. 2, 2002. More than a year later, on Jan. 2, 2004, Stardust flew by Wild-2, collecting samples of interstellar and comet dust, and two years after that, its sample-return capsule came to Earth in the Utah desert. Its samples are still being studied today. —**George Reynolds,** Virginia Beach, VA

Understanding comets

Walter Harris' excellent article, "The science of comets" (January 2023), discusses the current understanding of comet formation and their physical properties. The concept of amorphous water ice providing an internal energy source for comets was first proposed by me, along with Georg Rupprecht and Donald Schuerman, in 1974. I am pleased that the basic concept we put forth has become the leading hypothesis in light of the fact that it was not universally embraced by other cometary scientists at the time. Comet research, as well as other astronomical studies, can always produce surprises, so it remains a hypothesis until (hopefully) a direct core sampling of a comet produces the required measurements. —**Harvey Patashnick,** Albany, NY



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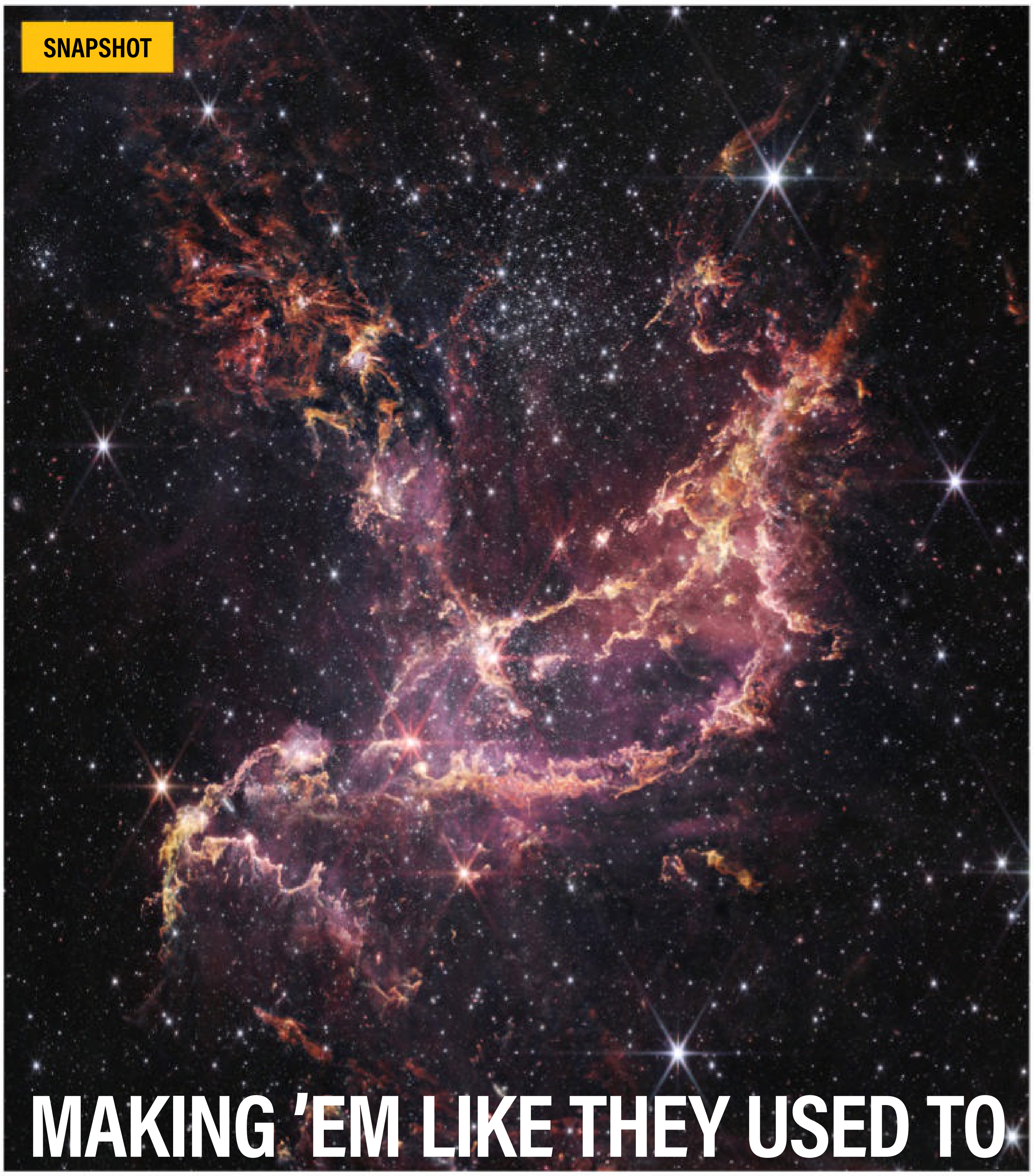


MAKING 'EM LIKE THEY USED TO

A nearby nebula sheds light on star formation during the universe's cosmic noon.

NGC 346 — tucked in the Small Magellanic Cloud (SMC), a dwarf galaxy close to the Milky Way — is one of the most curious star-forming regions in the nearby universe.

The SMC has an extremely low metallicity, meaning it lacks almost any elements other than hydrogen and helium. As such, it looks less like a modern galaxy and more like one that belongs in the 2-billion- to 3-billion-year-old universe. This period corresponds to a time called cosmic noon, when stars first began cropping up in droves following the Big Bang.

In the photo, the orange strands show dense, cold clouds of molecular hydrogen and dust feathering outward, creating an optimal environment for star and planet formation. The fluffier pink areas, meanwhile, highlight much hotter, more energetic clouds of hydrogen.

The fact that this region hosts the building blocks of both planets and stars means rocky planets may have formed earlier in the cosmic timeline than previously thought. –SAMANTHA HILL

HOT BYTES

HOMELESS STARS
Hubble recently showed that light from stars that are between galaxies within clusters is present in both old and young groups. This means stars are lost from their galaxies as clusters form, rather than stripped away over time.

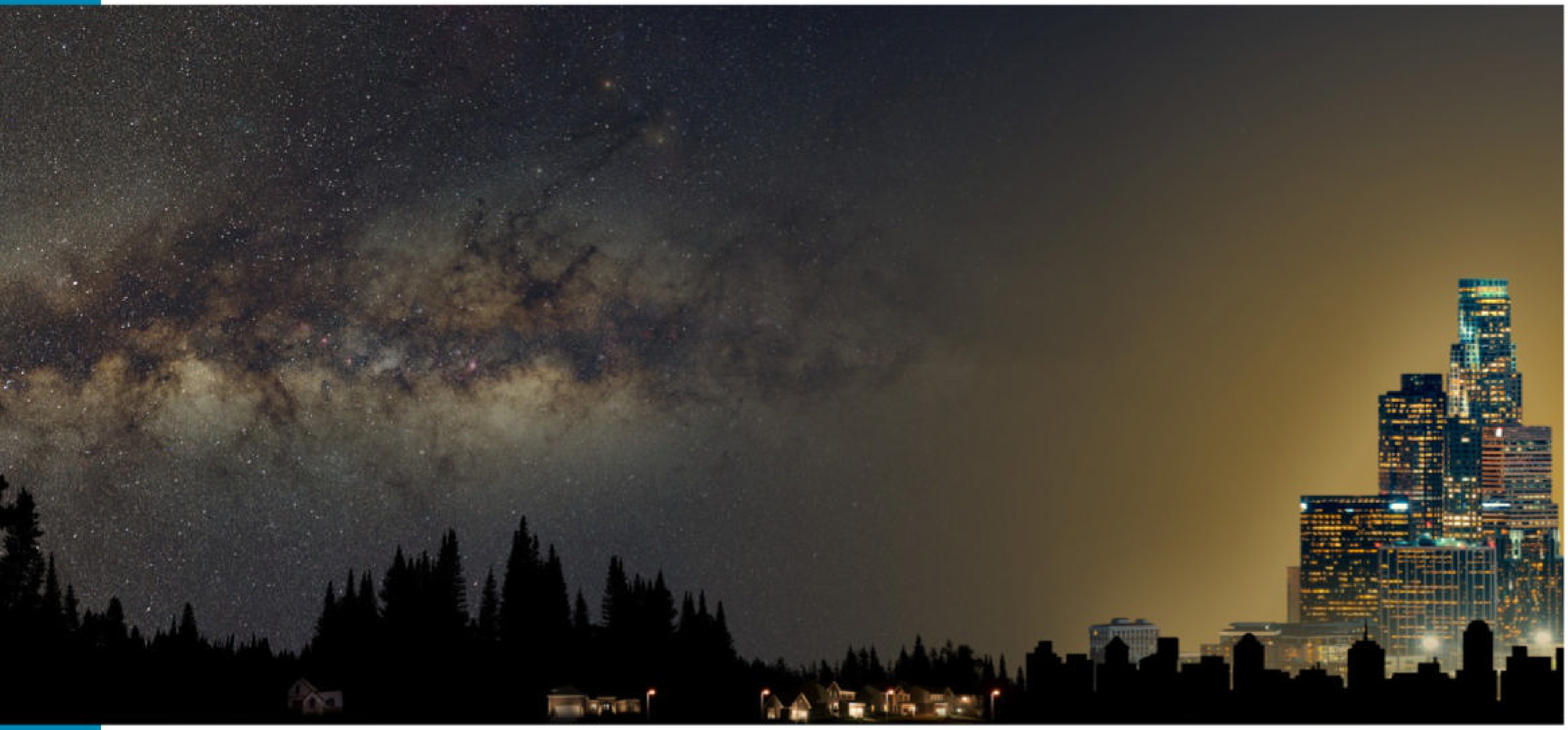
MOUNT MAGNETAR
A magnetar — a rapidly spinning, highly magnetic neutron star — suddenly slowed its spin and began emitting radio waves in October 2020. Astronomers speculate a volcano-like rupture on its surface might be to blame.

FAIL BRITANNIA
On Jan. 9, Virgin Orbit attempted the first ever orbital launch from the United Kingdom. But the rocket's upper stage suffered an anomaly, failing to lift the vehicle into orbit. Virgin Orbit has previously made four successful launches, all from California.

SCIENCE: NASA, ESA, CSA, OLIVIA C. JONES (UK ATC), GUIDO DE MARCHI (ESTEC), MARGARET MEIXNER (USRA); IMAGE PROCESSING: ALYSSA PAGAN (STSCI), NOLAN HABEL (USRA), LAURA LENKIĆ (USRA), LAURIE E. U. CHU (NASA AMES).
RIGHT TOP: SCIENCE: NASA, ESA, STSCI, JAMES JEE (YONSEI UNIVERSITY); IMAGE PROCESSING: JOSEPH DEPASQUALE (STSCI). RIGHT CENTER: NASA'S GODDARD SPACE FLIGHT CENTER. RIGHT BOTTOM: VIRGIN ORBIT

LIGHT POLLUTION INCREASING FASTER THAN THOUGHT

Satellite data fail to capture the loss of the naked-eye night sky.



LIGHTS UP. As scattered light from skyglow increases (from left to right), fewer stars become visible to the naked eye. NOIRLAB/NSF/AURA, P. MARENFELD

» Finding dark nighttime skies for observing is getting harder — and the rate at which dark skies are disappearing is faster than satellite-based measurements might indicate. This find comes from a *Science* paper published Jan. 19 and based on more than a decade of observations from around the world.

To determine how quickly the night sky is brightening, researchers developed the Globe at Night citizen science project. They gave 51,351 volunteers in 19,262 locations a star chart showing which stars are visible under varying levels of light pollution. The volunteers then regularly reported which chart best matched the sky from their location on cloudless, Moonless nights.

Those reports showed the sky is growing brighter at a rate of 7 to 10 percent per year, averaging out to a global decrease in night-sky darkness of 9.6 percent per year. "If the development were to continue at that rate, a child born in a place where 250 stars are visible will only be able to see 100 stars there on his 18th birthday," said lead author Christopher Kyba of the German Research Centre for Geosciences in Potsdam in a press release.

THREAT ON THE HORIZON. Light pollution from Tucson, Arizona, has been steadily encroaching on Kitt Peak National Observatory for decades. KPNO/NOIRLAB/NSF/AURA/B. TAFRESHI

The find stands in stark contrast to satellite observations, which suggest skyglow — diffuse scattered light that affects the stars' visibility — has been increasing at the more modest rate of 2 percent per year.

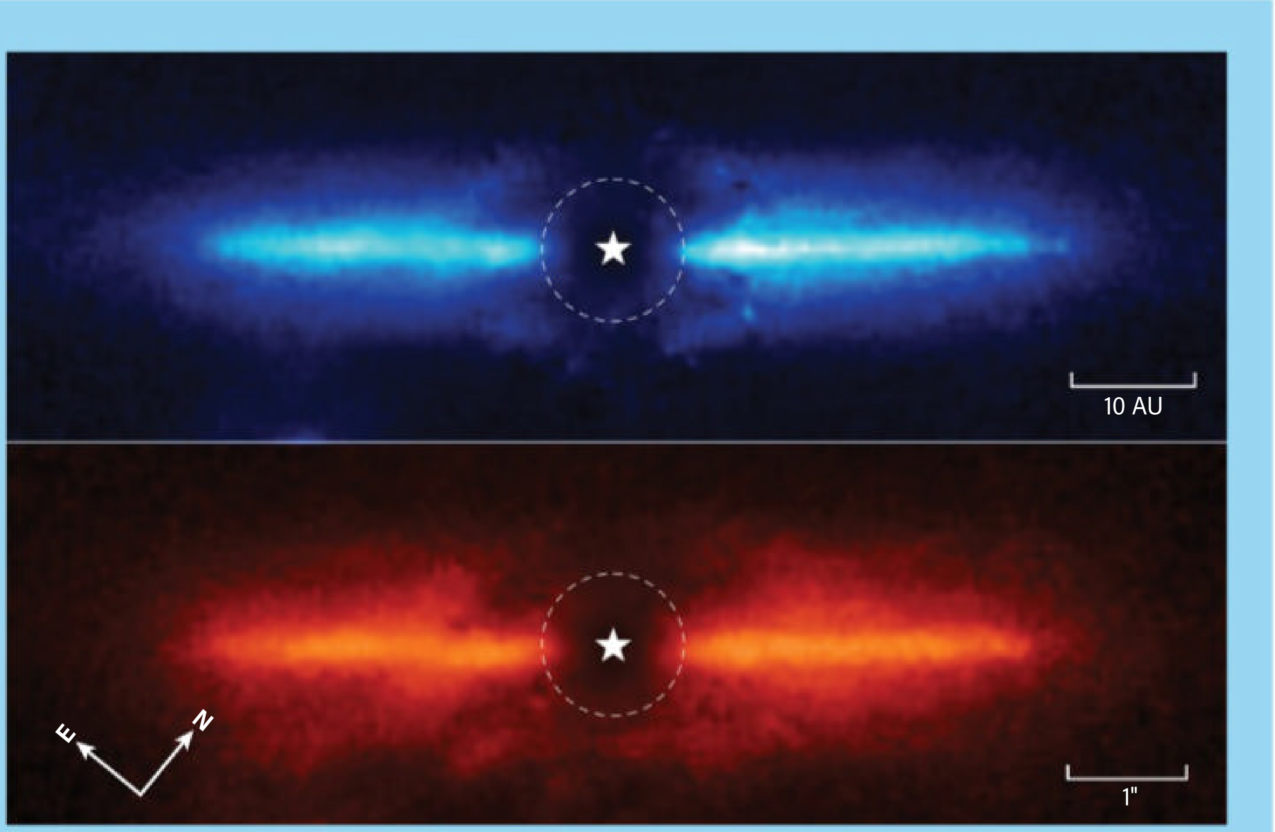
There are two main reasons for the difference, the authors say. Satellites largely see only light that is directed upward. However, light directed downward or horizontally — which constitutes the majority of new lighting — is most responsible for decreased night sky visibility from the ground. Additionally, the spacecraft currently observing Earth for skyglow do not measure bluer light, such as from LEDs, which is more susceptible to scattering in the atmosphere and heavily affects human vision.

The researchers do note that although they have volunteers across the globe, coverage is patchy in some areas and most participants are in areas with the heaviest light pollution, such as North America and Europe. More data are needed from a wider range of locations, including developing countries where artificial lighting is likely increasing but going unmeasured.

BRIGHTER NIGHTS AHEAD

These results come at a time when astronomers are voicing additional concerns over losing the dark night sky, including to megaconstellations of communications satellites. (See "The satellite-streaked sky" in our March 2023 issue for more.) SpaceX has regulatory approval to launch a total of 19,500 Starlink satellites and is planning to add roughly 22,500 more. These satellites operate at the edge of naked-eye visibility but still contribute to diffuse skyglow and interfere with professional observations. And in September 2022, AST SpaceMobile launched a prototype satellite called BlueWalker 3, which at times can outshine most naked-eye stars. A study in December 2022 in *Monthly Notices of the Royal Astronomical Society* found that of 28 observatories with telescopes larger than 3 meters, some two-thirds now experience light pollution levels of at least 10 percent above the ambient dark sky.

Scientists argue that increasing skyglow not only diminishes ongoing research and cultural heritage related to the night sky, but also negatively affects plants and animals. Understanding these impacts and how to mitigate them is increasingly a part of climate and cultural discussions. – ALISON KLESMAN



SCIENCE: NASA, ESA, CSA, KELLEN LAWSON (NASA-GSFC), JOSHUA E. SCHLIEDER (NASA-GSFC). IMAGE PROCESSING: ALYSSA PAGAN (STSCI)

Zooming in on a microscope

The dusty debris disk of AU Microscopii, located a mere 32 light-years away, glows in new images from the James Webb Space Telescope (JWST). Using a coronagraph — an instrument that can block light from the central star (whose location is shown here by a white graphical star) — astronomers imaged the disk with two different infrared filters. The blue image shows infrared light at 3.56 microns and reveals fine-grained dust. The red image shows a wavelength of 4.44 microns and traces coarser grains. The blue image is brighter, meaning there is more fine dust than coarse. Astronomers were able to view the disk down to about 460 million miles (740 million kilometers) from the star — roughly the distance of Jupiter from the Sun. While that may seem far, it's razor-sharp viewing for distant star systems and bodes well for JWST's ability to spot Jupiter or Saturn analogues in other systems. Astronomers know from previous observations that AU Mic has two planets, both located well within the coronagraph's black-out zone. – KOREY HAYNES

QUICK TAKES

NEXT-NEXT GEN

NASA has unveiled plans for the Habitable Worlds Telescope, a 6-meter observatory capable of detecting signs of life on nearby Earth-like exoplanets. Like JWST, it will operate at L2, some 930,000 miles (1.5 million km) from Earth — but unlike JWST, it will be designed to be serviced and upgraded by robotic craft.

RED ERRING

The cores of active galaxies, whose supermassive black holes are gorging on material, may be more energetic than previously appreciated, says a study of the galaxy NGC 5548. Their dusty environments make them appear redder — and dimmer — than they actually are.

A PERFECT STORM

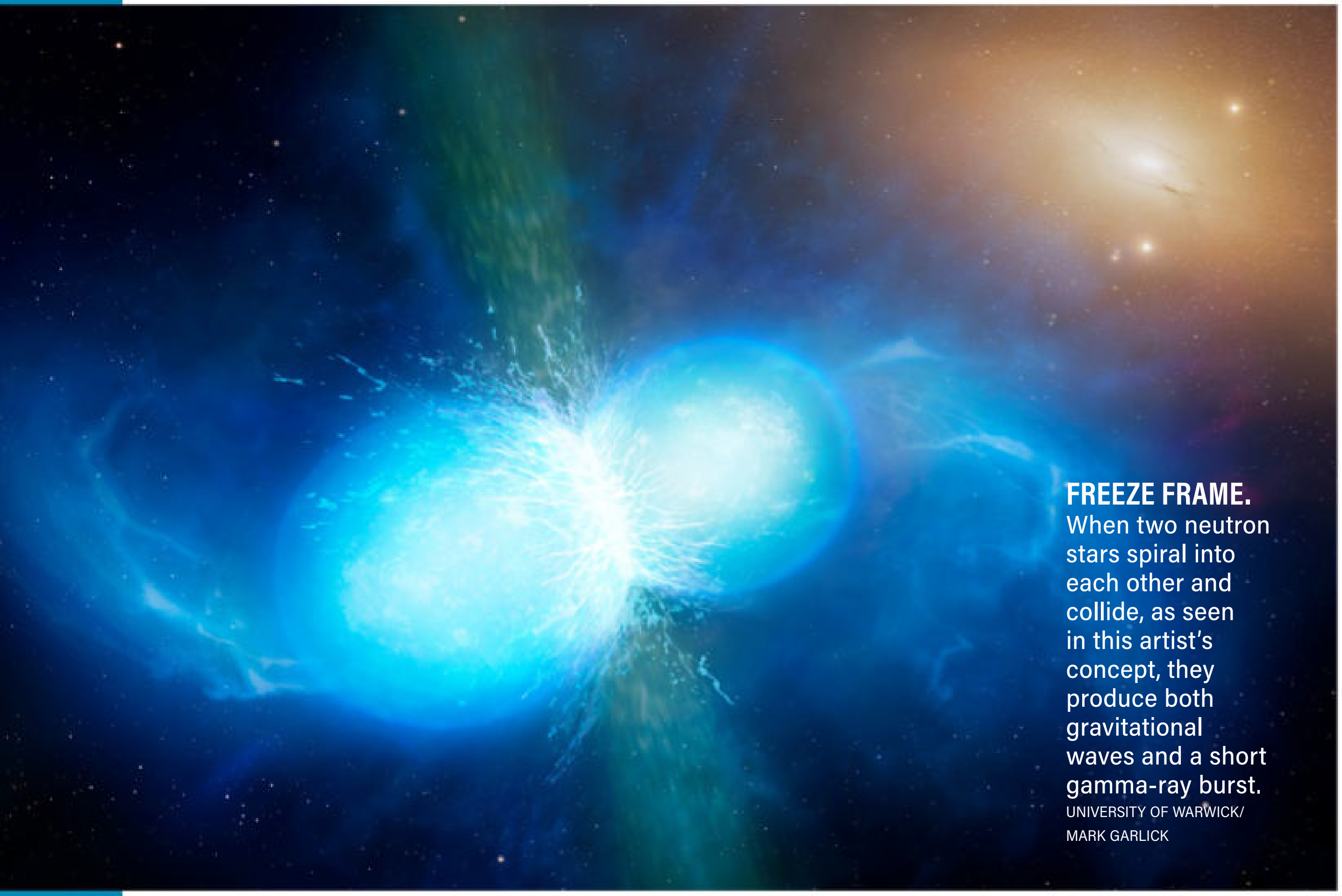
Like storm systems on Earth that merge and grow, ejections of plasma from the Sun that cause potentially harmful space weather events can become dramatically stronger if they collide just before striking Earth, according to new simulations.

DINNER FOR TWO

The nearby galaxy UGC 4211 has not one but two supermassive black holes (SMBHs) at its core, just 750 light-years apart. They're the closest SMBH binary known. UGC 4211 is the product of a galaxy merger and lies 500 million light-years away in Cancer.

INCREASED COOPERATION

The National Science Foundation and SpaceX signed an agreement, announced Jan. 10, to continue work to reduce the impact of Starlink satellites on ground-based observatories, including interference with radio astronomy. The firm also waived its right to have lasers in adaptive optics systems turned off when a Starlink satellite flies overhead, as is currently required. – MARK ZASTROW



FREEZE FRAME. When two neutron stars spiral into each other and collide, as seen in this artist's concept, they produce both gravitational waves and a short gamma-ray burst. UNIVERSITY OF WARWICK/MARK GARLICK

Clues to hypermassive neutron stars

» If you could freeze a film of two neutron stars just after they collide, you would see an object so massive and dense it shouldn't exist: a single neutron star spinning so fast it can briefly hold itself up against gravitational collapse. Just a split second later, the star would be gone, sucked into itself and replaced by a black hole.

These short-lived objects — called hypermassive neutron stars (HMNSs) — offer a fascinating, fleeting glimpse of the dynamics of a neutron star merger and the formation of a black hole. But gleaning information about them is difficult. Gravitational-wave detectors can observe the pre-collision neutron stars etching ripples into space-time as they spiral toward each other. But the current generation of detectors can't see ripples from the HMNS itself. To find signals from these objects, a team led by Cecilia Chirenti of the University of Maryland in College Park instead dove deep into the bursts of gamma rays that these mergers give off.

Because an HMNS is still "shaking and jiggling" from the violent merger, Chirenti tells *Astronomy*, it should produce a flicker in the gamma-ray burst signal — an oscillation in brightness that tends to repeat at a few frequencies. Chirenti compares these quasi-periodic oscillations (QPOs) to hearing an orchestra tune its instruments before a concert: Not everyone is totally in tune, but you can make out some frequencies that are stronger than others. By determining the peak frequencies of this flickering, astronomers can learn the size and spin rate of the HMNS.

The team analyzed more than 700 gamma-ray bursts and found QPOs in two of them, designated GRB 910711 and GRB 931101B. Both events had been observed by NASA's Compton Gamma-Ray Observatory in the 1990s.

Their analysis, published Jan. 9 in *Nature*, found that for both objects, the strongest oscillations were at a frequency of roughly 2,600 hertz. This suggests that the HMNSs are spinning at least 1,300 times per second, nearly twice as fast as the fastest known pulsar. — M.Z.

ROBERT FESEN

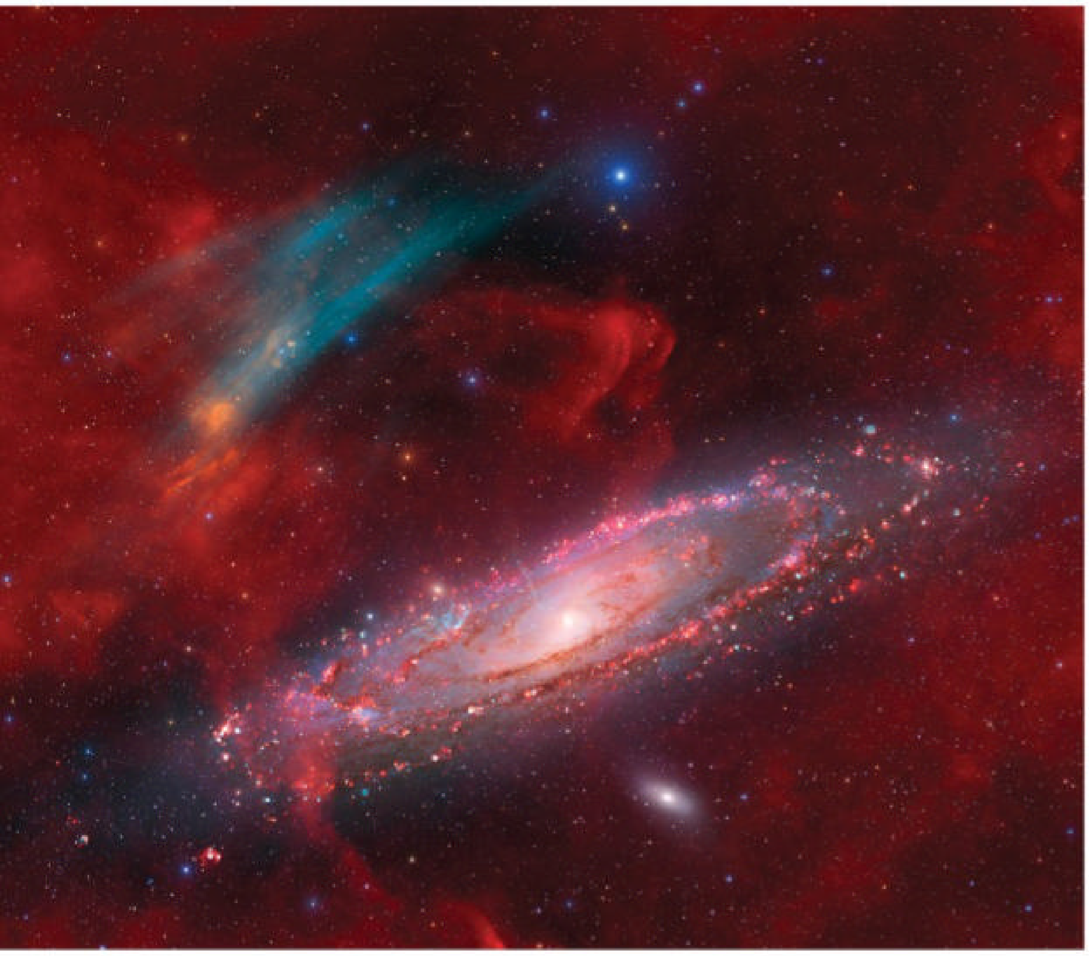
FIREWORKS FLY FROM SUPERNOVA

Planetary nebula Pa 30 was discovered by amateur astronomer Dana Patchik in 2013. But fresh data from astronomers Robert Fesen of Dartmouth University and Bradley Schaefer of Louisiana State University using a Sulfur-II filter have revealed stunningly sharp filaments of emission. The contrails appear to form from debris driven outward by the strong wind of the central star, which may be a remnant of a rare type Iax supernova recorded in 1181 by Chinese and Japanese astronomers. — M.Z.

17

The number of hours in a year for a pair of ultracool dwarf stars called LP 413-53AB, which have the tightest orbit of any such binary system yet found.

Astroimagers nab nebula near Andromeda



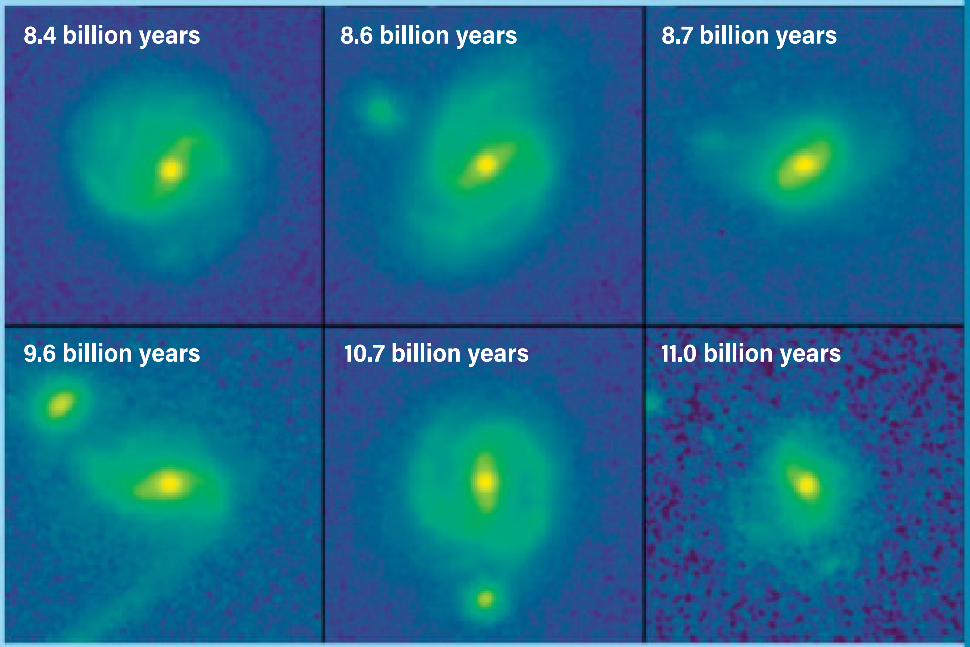
MARCEL DRECHSLER/XAVIER STROTTNER/YANN SAINTY

A group of amateur astronomers has uncovered a surprise lying next to one of the most venerable objects in the night sky: a previously unknown emission nebula just southeast of the Andromeda Galaxy (M31) and spanning half the width of the galaxy itself.

The feature, seen at upper left in the photo, was discovered in images taken last year with an Oxygen-III filter by French astroimager Yann Sainty, who worked with fellow observers Marcel Drechsler and Xavier Strottner to process and analyze the data. The image represents over 111 hours of exposure with a 4.2-inch Takahashi refractor and a CMOS astronomical camera. Working with professional astronomers and other astroimagers, the trio verified the find and published their results in *Research Notes of the American Astronomical Society* in January.

Researchers aren't yet sure if the object is physically related to M31; it could be galactic cirrus in the Milky Way. Either way, it highlights the role that amateur astronomers and imagers can play in astronomy — especially in discovering faint, extended emission. –M.Z.

MIRRORS INTO THE PAST



BAR CHART. Researchers identified six barred spiral galaxies, seen here, in new observations by the James Webb Space Telescope. The time it took for light from each galaxy to reach us is shown at upper left. NASA/CEERS/UNIVERSITY OF TEXAS AT AUSTIN

NEW IMAGES from the James Webb Space Telescope (JWST) reveal two galaxies in the distant, early universe that sport long bars stretching between their spiral arms, a first-of-its-kind find for galaxies so young.

Barred spiral galaxies are not unusual in the modern universe. Bars are a sign that a galaxy has reached maturity; nearly 70 percent of nearby spiral galaxies have bars, including our own Milky Way. However, the barred spirals JWST spotted existed at a time when the universe was just a quarter its current age.

The find is detailed in an article accepted for publication in *The Astrophysical Journal Letters*. In it, researchers used JWST data from the Cosmic Evolution Early Release Science (CEERS) Survey to identify six strong examples of barred galaxies that appear more than 8 billion years ago. The two most distant of these galaxies — EGS-23205 and EGS-24268 — existed some 11 billion years ago, when the universe was less than 3 billion years old.

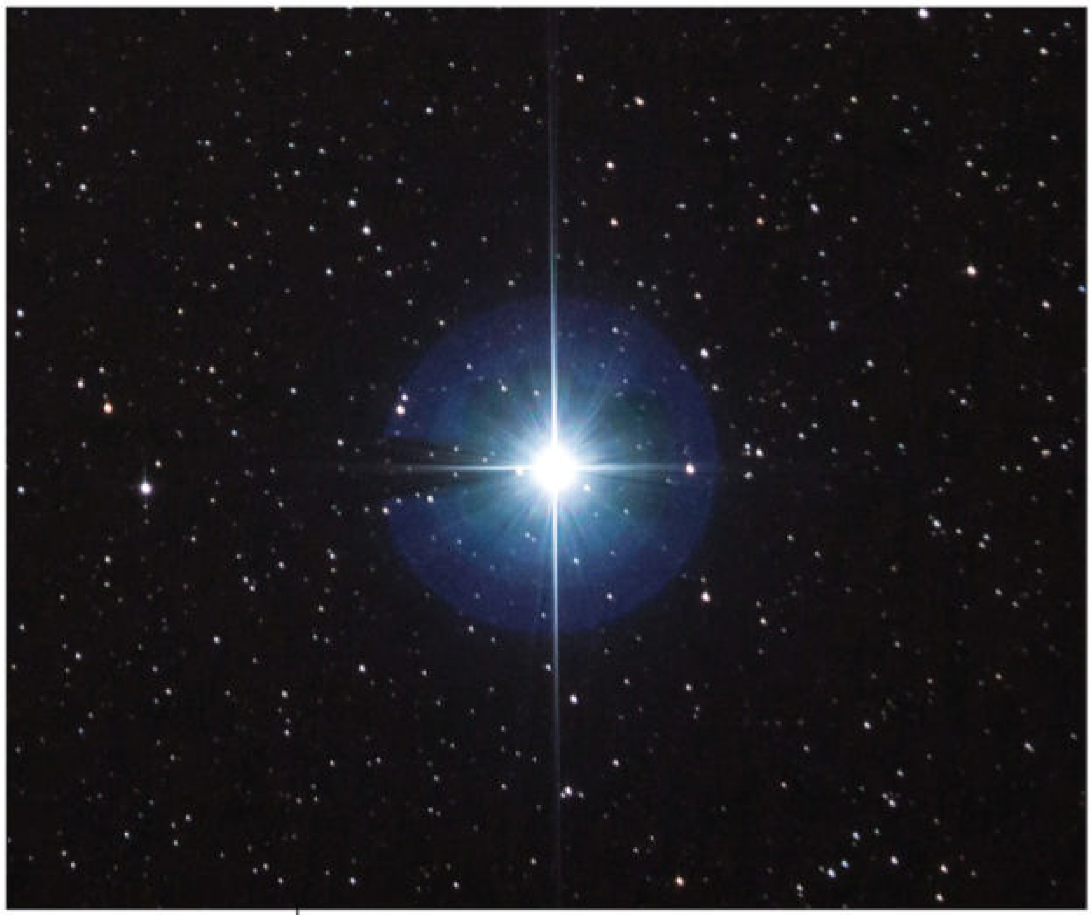
Bars are important because they help funnel gas into the central regions of a galaxy, which both boosts star formation and speeds up the growth of the galaxy's central supermassive black hole.

"Bars solve the supply chain problem in galaxies," Shardha Jogee, an astronomer at The University of Texas at Austin and co-author of the new study, said in a press release. "Just like we need to bring raw material from the harbor to inland factories that make new products, a bar powerfully transports gas into the central region where the gas is rapidly converted into new stars at a rate typically 10 to 100 times faster than in the rest of the galaxy."

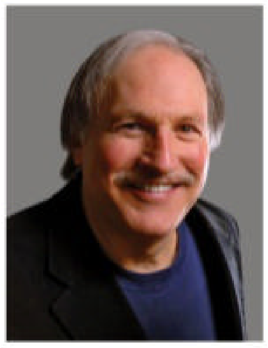
Because astronomers have now observed these transport structures in galaxies from the relatively early universe, they might need to update their theories and models related to galaxy evolution. –JAKE PARKS

For your reference

There are plenty of celestial Post-its to use as starting points in the sky.



The bright star Vega serves as the zero point on many astronomical scales. STEPHEN RAHN



BY BOB BERMAN
Bob's recent book, Earth-Shattering *(Little, Brown and Company, 2019), explores the greatest cataclysms that have shaken the universe.*

To astro-beginners, the night sky can seem like a funhouse of random dots. For those starting out in the astronomy hobby — maybe you bought a cool telescope and suddenly want to know the sky — there can seem little rhyme or reason beyond the easy-peasy patterns like the Big Dipper and Orion's Belt.

Once you learn just a little more, you may start to realize that the sky can be cataloged. But while it can be simple to learn, say, the stars and constellations, it's harder to get rock solid when it comes to things like locating the celestial equator or knowing the B-V star color system. It sure would be nice if someone had stuck a few Post-it notes up there.

Well, guess what? Someone sort of did.

Let's explore celestial reference points using stars you already know. Take the magnitude system, for example. We've all gotten used to the counterintuitive fact that the higher a star's magnitude, the fainter it is. The dimmest naked-eye stars are usually listed as magnitude 6 while the very brightest, Sirius, is magnitude –1.5, a negative number.

But what is the system's starting point? Where is zero?

It's Vega, the brightest star of the great Summer Triangle. Stellarium and some other catalogs list it as magnitude 0.00, a zero right on the nose. Other references place it a few hundredths of a degree higher, but still exactly 0.0 when rounded to the nearest tenth of a magnitude. But Vega goes beyond being a reference point for stellar brightness. On the B-V star-color scale, which drifts from higher positive numbers for redder stars to negative numbers for blue ones, Vega's B-V color index is 0.00. Amazingly, Vega is a reference point for star color, too! It's like the platinum bar in France once used to define the standard meter.

There's even more. It's hard to visually pinpoint the zenith, the spot precisely overhead. Well, Vega comes close to that position for everyone who lives between 35° and 42° north latitude, meaning much of the U.S. For those many millions of observers, Vega sits within 2° of the exact zenith every single day or night.

But don't get too comfortable — Vega is not the zero point of every system. For instance: Let's explore the celestial equator, the imaginary line that's straight overhead for everyone on Earth's equator. Only stars on the celestial equator can be seen by everyone in the world — even the Arctic and the Antarctic. To locate this important celestial marker, whose declination is zero, simply identify one of the bright stars that sit less than a degree from it. Here, your reference stars are the rightmost member of Orion's Belt, Mintaka, which is less than a third of a degree below the celestial equator; and the brightest star of Aquarius, Sadalmelik, which is also less than a third of a degree below the sky's midpoint. And there's even a third one: Zeta (ζ) Virginis, the Virgo star to the upper left of bright Spica. It hovers just over half a degree below that reference line.

Let's explore celestial reference points.

Now, let's talk motion. If you want to know which way the Sun and Earth are zooming through space, all you need to do is look back to Vega. Yep — let's award that Summer Triangle star yet another distinction. Our speed toward that part of the sky is 1⁄13 of the Sun's 144 mile-per-second (232 kilometers per second) orbital motion around the galactic center, so it's like a bit of a sideslip as we partake of the Milky Way's rotation.

Let's end with something more local. How about our orbital motion around the Sun? Which way is that carrying us? That one's easy if you're vacationing in the tropics. At dawn, simply look overhead, and you're in the pilot's seat in our orbit, facing forward on Starship Earth.

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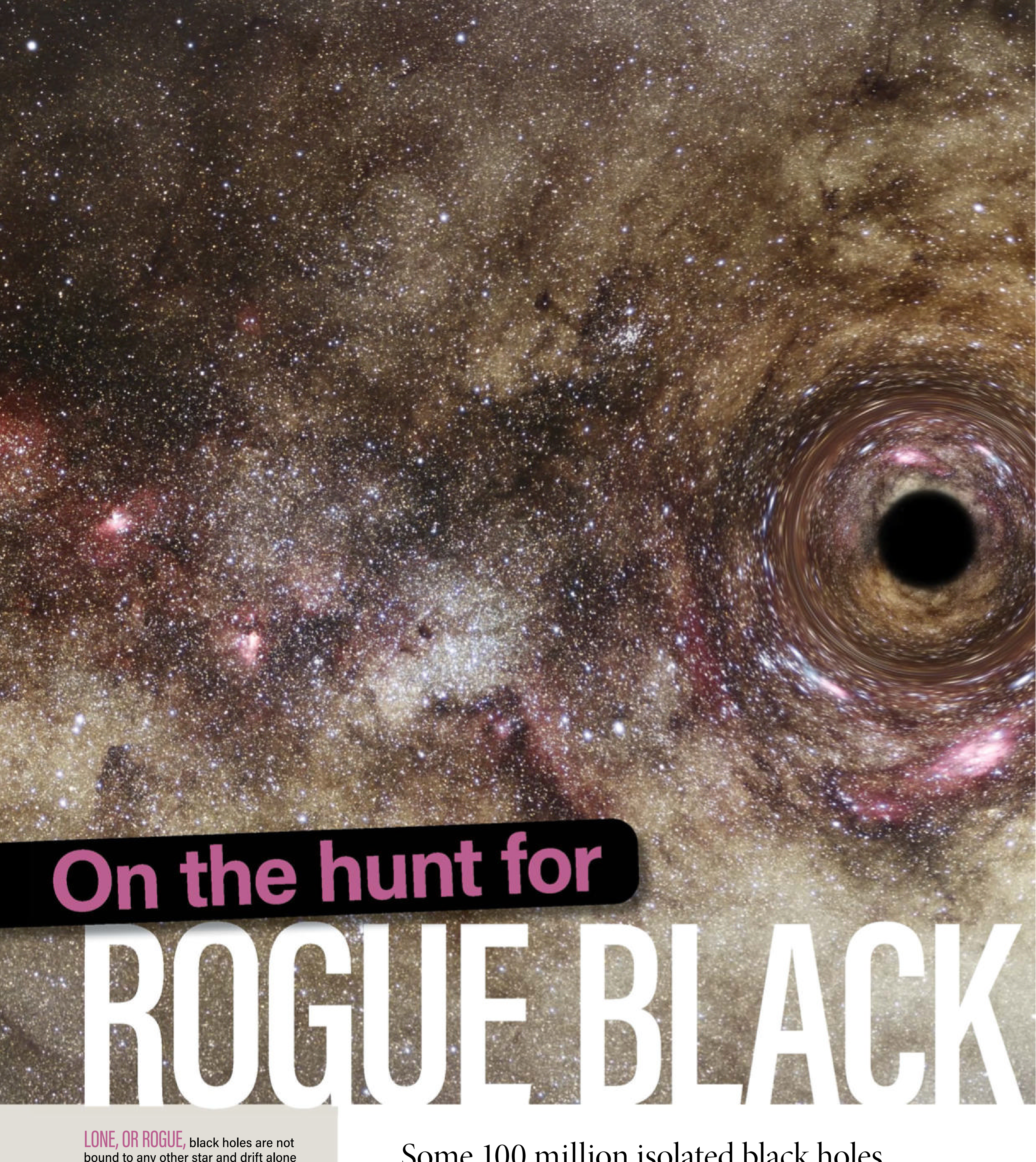
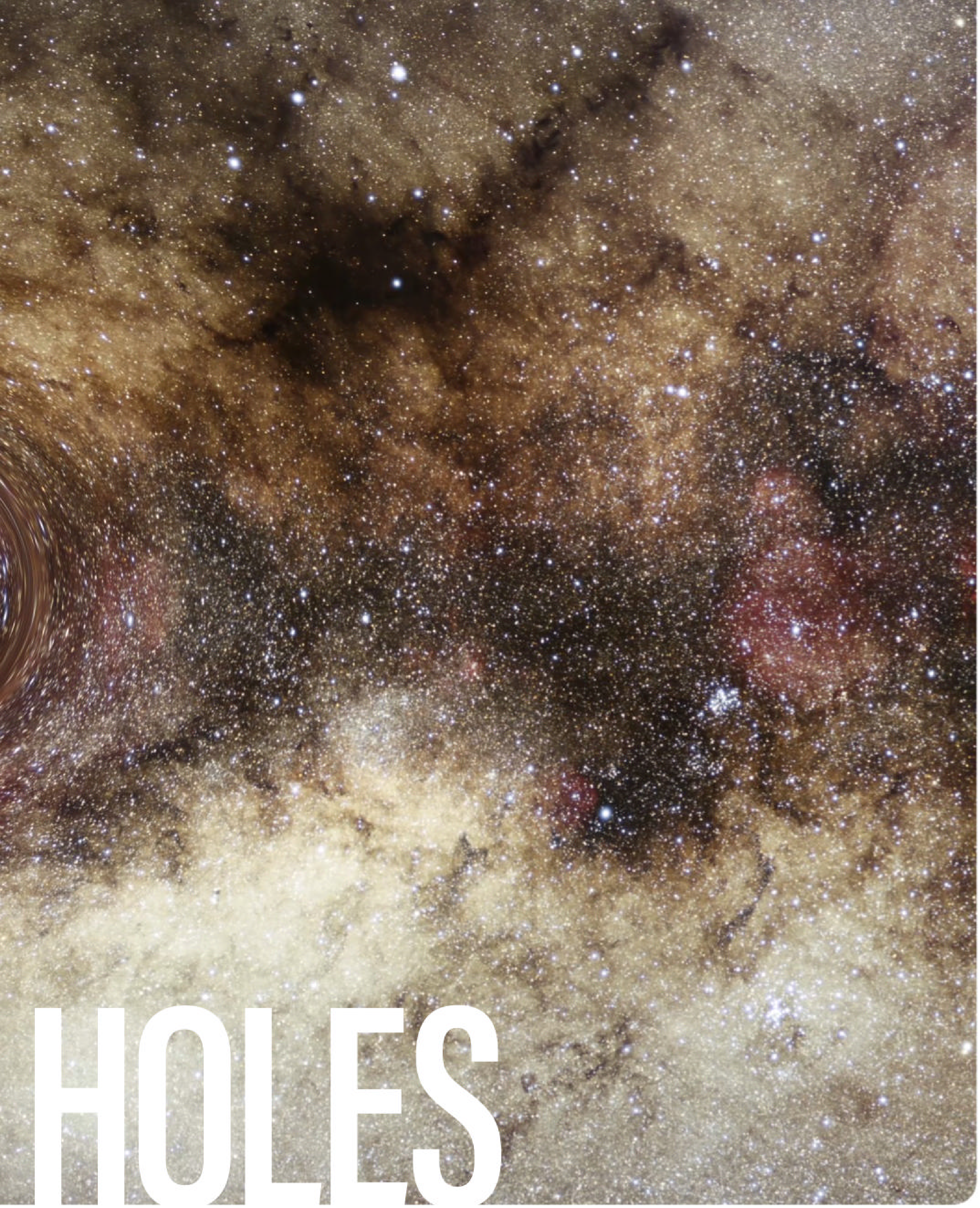


On the hunt for ROGUE BLACK

LONE, OR ROGUE, black holes are not bound to any other star and drift alone through space. Without a ready food source, they have minimal accretion disks and appear truly dark, making them exceedingly difficult to find. However, their immense gravity warps space-time, as seen in this artist's concept, and can give these objects away when they pass in front of a visible star from Earth's point of view. ESA/HUBBLE, DIGITIZED SKY SURVEY, NICK RISINGER (SKYSURVEY.ORG), N. BARTMANN

Some 100 million isolated black holes lurk within the Milky Way. We're finally starting to bring them into the light.

BY ASHLEY BALZER VIGIL

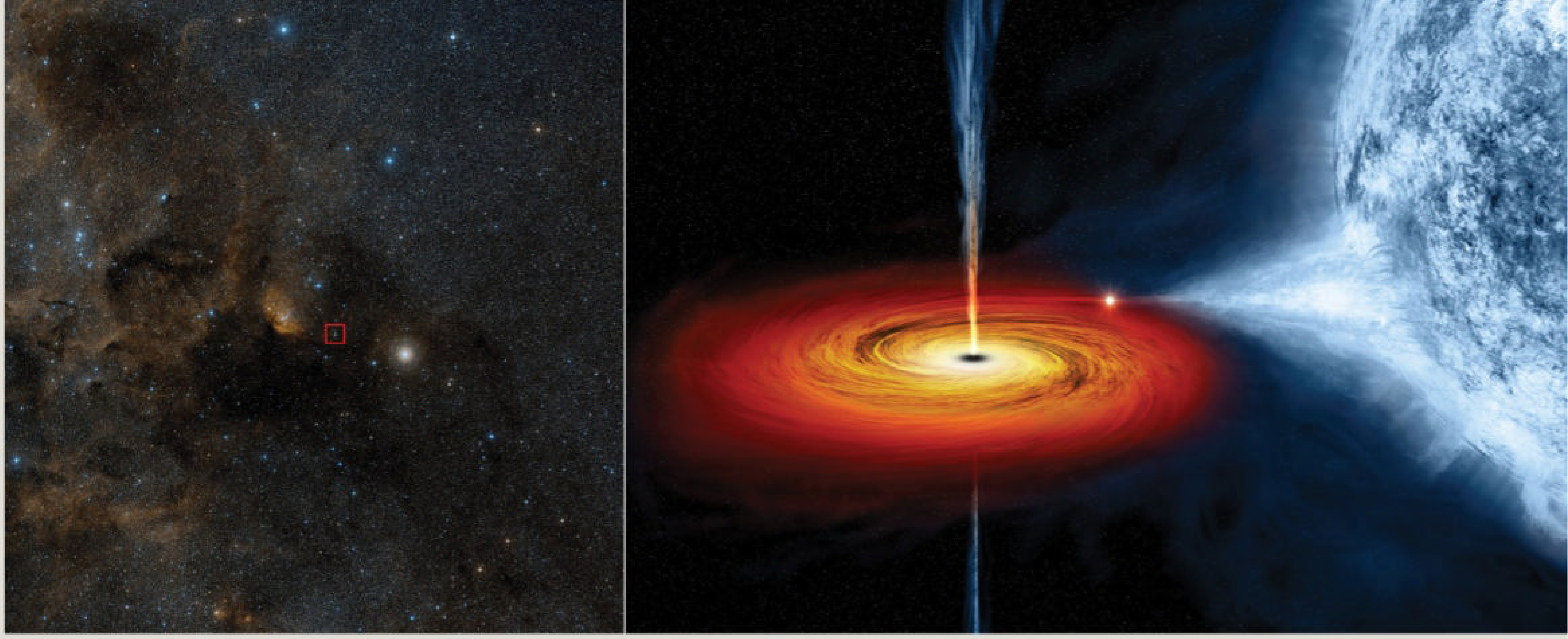


HOLES

ON A COOL EVENING in a small village in India, a man sat with his son and stared up at the night sky, as was their habit after dinner. Since the village had no electricity, the stars shone extra bright against the inky backdrop of space. The two spoke of stellar motions, and the young boy soon developed a fascination for astronomy.

Neither of them knew then that this fascination would one day dramatically advance our understanding of the cosmos. A few decades later, in 2022, Kailash Sahu — the young boy from India — would lead a team to discover the first known "rogue" black hole.

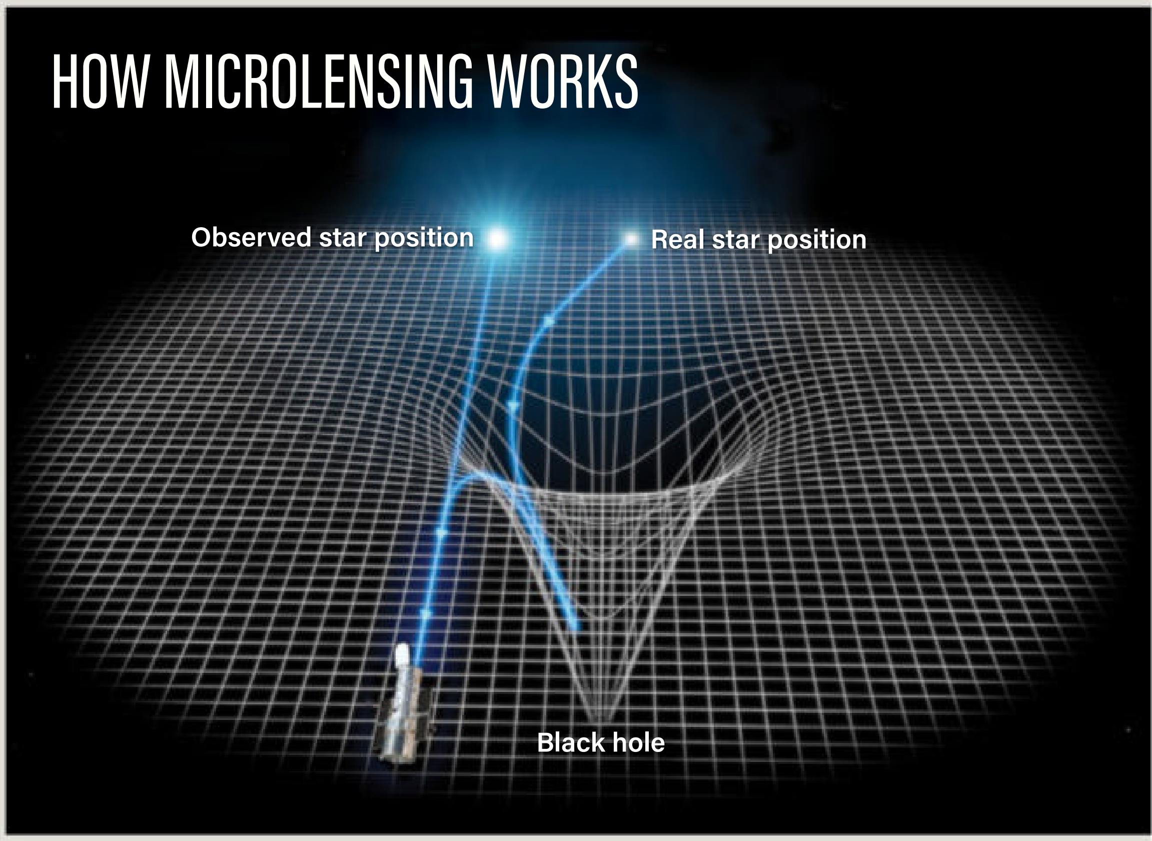
Although it's been more 50 years since the first detection of a black hole, these objects are still more



CYGNUS X-1 is a stellar-mass black hole in a binary system with the star HDE 226868. The pair resides within the region outlined in red in the photo at left, near Eta (η) Cygni. The artist's illustration at right shows a close-up view of the black hole and its accretion disk (orange, yellow), formed as it pulls material from its companion star. This disk is so hot that it shines in X-rays, giving away its position. OPTICAL: DSS; ILLUSTRATION: NASA/CXC/M.WEISS

commonly theorized about than observed. Astronomers have identified just a few dozen stellar-mass black holes in our galaxy — and only then because they are in binary systems, pulling material from a still-shining companion star. And these may be the extreme exceptions, not the rule. Most of the 100 million or so black holes thought to exist in the Milky Way drift through space alone, quiescent, dark, and impossible to spot directly.

But with Sahu's discovery of such a rogue black hole, astronomers have begun to uncover that vast unseen majority, promising a revolution in the field and insight into the objects' origins.



A MICROLENSING EVENT occurs when a massive object, such as a black hole, passes in front of a background star. The foreground object's gravity warps space-time around it, which both brightens and displaces the image of the background star. Measuring the length of the event, the amount of brightening, and the apparent displacement of the star can tell astronomers the mass of the foreground lens — in this case, a black hole some seven times the mass of the Sun. NASA, ESA, STSCI, JOSEPH OLMSTED

Black holes 101

The idea of an object whose gravity is so strong that not even light can escape its grasp was first introduced by John Mitchell in the late 1700s. However, such objects were long thought to be a mathematical quirk that had little to do with reality. Karl Schwarzschild, a German physicist and astronomer, further developed the mathematical concept of black holes in 1916 after working through Einstein's equations of relativity. But for decades, most experts didn't think they could actually form. The English astronomer Arthur Eddington once said, "I think there should be a law of nature to prevent a star from behaving in this absurd way!"

It's easy to see why astronomers took some time to get on board. Black holes are some of the most bizarre objects in the cosmos, throwing our earthly concepts of space and time right out the window. Each one packs the mass of an entire star (or many stars) into a vanishingly small space called a singularity. Surrounding it is the event horizon — the boundary of no return, inside which even the speed of light isn't fast enough to escape the pull of gravity. The size of a black hole — i.e., the distance of the event horizon from the singularity — depends on the mass of the black hole.

It gets even stranger. Einstein taught us that space and time are interlocked; warping one warps the other too. As a result, time moves more and more slowly the deeper you get in the gravitational well of any massive object, be it a star or a black hole. But black holes are uniquely odd: Once you reach the event horizon, time screeches to a halt, as viewed by an outside observer. (For the unfortunate individual falling into the black hole, time marches on.) Because of this, some physicists originally called black holes "frozen stars" and presumed that such mind-bending objects couldn't be real.

You might understand, then, how physicists reacted with widespread skepticism when the first black hole was discovered. The journey began in 1964, when a sounding rocket experiment detected an unseen object emitting lots of X-rays. That fit the profile of a black hole, around which infalling gas grows extremely hot — so hot that it emits X-rays before ultimately falling past the event horizon.

The object, dubbed Cygnus X-1, or Cyg X-1 for short, was in a binary system with a companion star. That binary nature allowed astronomers to determine the mass of the unseen object by applying Kepler's laws of motion to the visible star. Based on the results, they realized there was no other alternative — it could only be a black hole. Scientists were forced to accept that these ghostly goliaths were real after all.

A 'rogue' black hole

Today, scientists think our galaxy is teeming with millions of black holes born from the collapse of massive stars. But since they're invisible, astronomers have only been able to detect a few — around 20 to date — thanks to the presence of companion stars.

That is, until July 2022.

That's when a team of scientists led by Sahu, now an astronomer at the Space Telescope Science Institute in Baltimore, published the first-ever confirmed detection of a stellar-mass black hole that's completely alone. Their results, which appeared in *The Astrophysical Journal*, raise the possibility of finding more of the estimated 100 million such rogue stellar-mass black holes drifting through our galaxy unseen.

Located about 5,200 light-years away toward the center of our galaxy, the yet-to-be-named rogue black hole weighs in at just over seven times the Sun's mass. It's also moving along at some 28 miles (45 kilometers) a second, faster than nearly all the stars in the region.

That speed hints at how it formed. Scientists think that when a massive star runs out of fuel and collapses into either a neutron star or a black hole, the supernova explosion it experiences may be uneven. "This black hole seems to have gotten a natal kick at birth that sent it speeding away" from any nearby stars, says Sahu.

Confirming
THE ROGUE

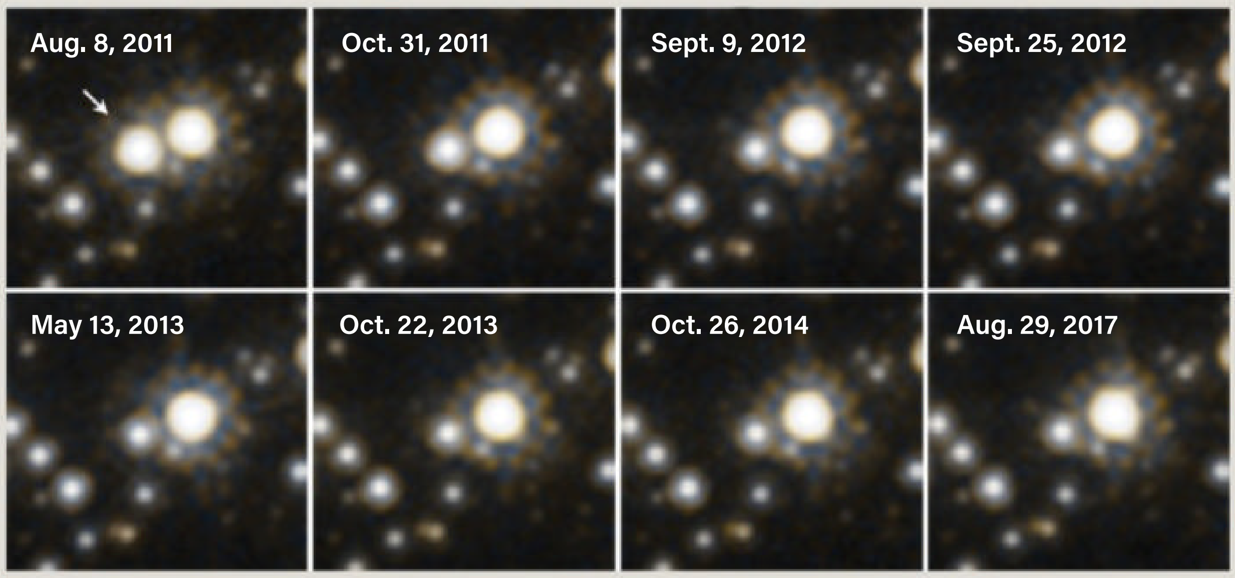
A TEAM led by Casey Lam and Jessica Lu of the University of California, Berkeley, published a study including the same rogue black hole candidate in July 2022 in *The Astrophysical Journal Letters*. They found the object was between 1.5 and 4 solar masses — possibly light enough to be a neutron star. However, another July 2022 paper in *The Astrophysical Journal* indicated its lack of X-rays disfavored a neutron star. And an independent analysis published in October 2022 in *The Astrophysical Journal Letters* is consistent with Sahu's mass, further clinching the case for a rogue black hole.
—Alison Klesman

Seeing the unseeable

This discovery was the culmination of six years of observations and two different techniques.

First, Sahu's team looked in the galactic center for stars that grew temporarily brighter because of an effect called microlensing. We know that massive objects warp the fabric of space-time around them. When a heavy object passes in front of a more distant star along our line of sight, the background starlight bends as it travels past the closer object. This both distorts the observed position of the star from our point of view and acts as a natural magnifying glass, brightening the star's light.

The phenomenon is called gravitational lensing, or microlensing when the foreground object, or lens, is small (like a star, neutron star, or black hole). Astronomers can roughly estimate the mass of the lens by watching how long the spike in starlight lasts; heavier objects create longer microlensing events.



A PASSING BLACK HOLE left its telltale mark on a star in the galactic center (indicated in the first image with an arrow), causing the star to brighten and shift its apparent position over several years. The shift was so small, it could only be measured using the Hubble Space Telescope. By 2017, the star had very nearly returned to its original brightness and location. SAHU ET AL. 2022, AN ISOLATED STELLAR-MASS BLACK HOLE DETECTED THROUGH ASTROMETRIC MICROLENSING, DOI 10.3847/1538-4357/AC739E

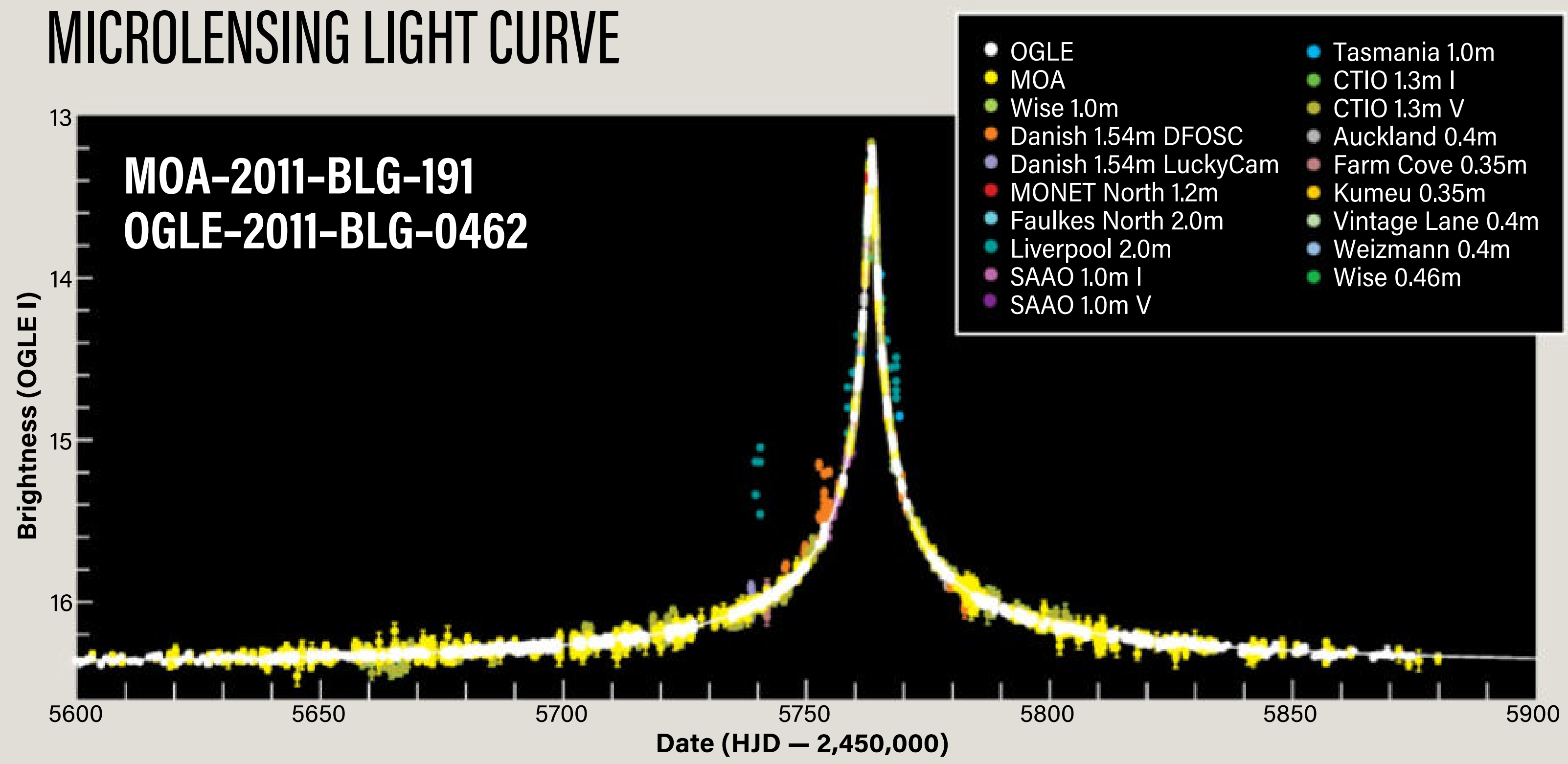
THE OPTICAL Gravitational Lensing Experiment (OGLE) is one of two telescopes that first detected the original microlensing event, called MOA-11-191/OGLE-11-462, which led to the discovery of the rogue black hole. KRZYSZTOF ULACZYK/WIKIMEDIA COMMONS

Two ground-based telescopes, the Optical Gravitational Lensing Experiment (OGLE) in Chile and Microlensing Observations in Astrophysics (MOA) telescope in New Zealand, initially picked up the microlensing event, since cataloged as MOA-11-191/OGLE-11-462. It lasted long enough — 270 days over 2011 and 2012 — that astronomers suspected the lens could be a black hole.

But a black hole can't be confirmed by microlensing alone. A small, faint star can masquerade as a heavier object if it is moving slowly; it, too, would produce a long signal due to its slow speed, and if it's dim enough, astronomers might only detect light from the background star.

That's where astrometry — making precise measurements of an object's position — comes in. By seeing how much the background star appears to shift during a microlensing event, astronomers can more accurately determine the mass of the lens.

The team spent six years watching and analyzing the astrometric signal, which in general can last five to 10 times longer than its microlensing counterpart. The deflection of the background star's position reached a maximum of about 0.002" — some 30 times less than the smallest Pluto can appear from Earth. Only the Hubble


MICROLENSING LIGHT CURVE

THIS GRAPH shows the light curve, or change in brightness over time, that marks the microlensing event caused by the rogue black hole, as observed by many ground-based telescopes. The narrow peak magnification occurred over a seven-day period, while the entire event lasted some 270 days — already an indication it was caused by a massive object, as more massive lenses cause longer microlensing events. *ASTRONOMY*: ROEN KELLY, AFTER SAHU ET AL. 2022, AN ISOLATED STELLAR-MASS BLACK HOLE DETECTED THROUGH ASTROMETRIC MICROLENSING, DOI 10.3847/1538-4357/AC739E

Space Telescope is capable of detecting a deflection that minute. But it was large enough to indicate that the foreground object was "so massive that if it were a star, it would be shining brightly; yet, we detected no light from it at all," says Sahu. "That's how we knew we found a black hole."

"It's extremely gratifying to be part of such a monumental discovery," he says. "I've been searching for rogue black holes for more than a decade, and it's exciting to finally find one! I hope it will be the first of many."

Those future finds may come from NASA's Nancy Grace Roman Space Telescope, planned to launch by 2027. The observatory will stare toward the heart of our galaxy, where stars are packed close together, looking for microlensing signals like the one Sahu's team spotted. This survey will reveal a host of unseen objects, from planets orbiting stars to potentially more rogue black holes.

Any additional detections will help astronomers understand stellar-mass black holes in ways they can't from just the couple of dozen that are currently known. Just as an online shopper gains confidence from a high number of product reviews, astronomers want to gather a statistical sample that more accurately represents what stellar-mass black holes are like as a group.

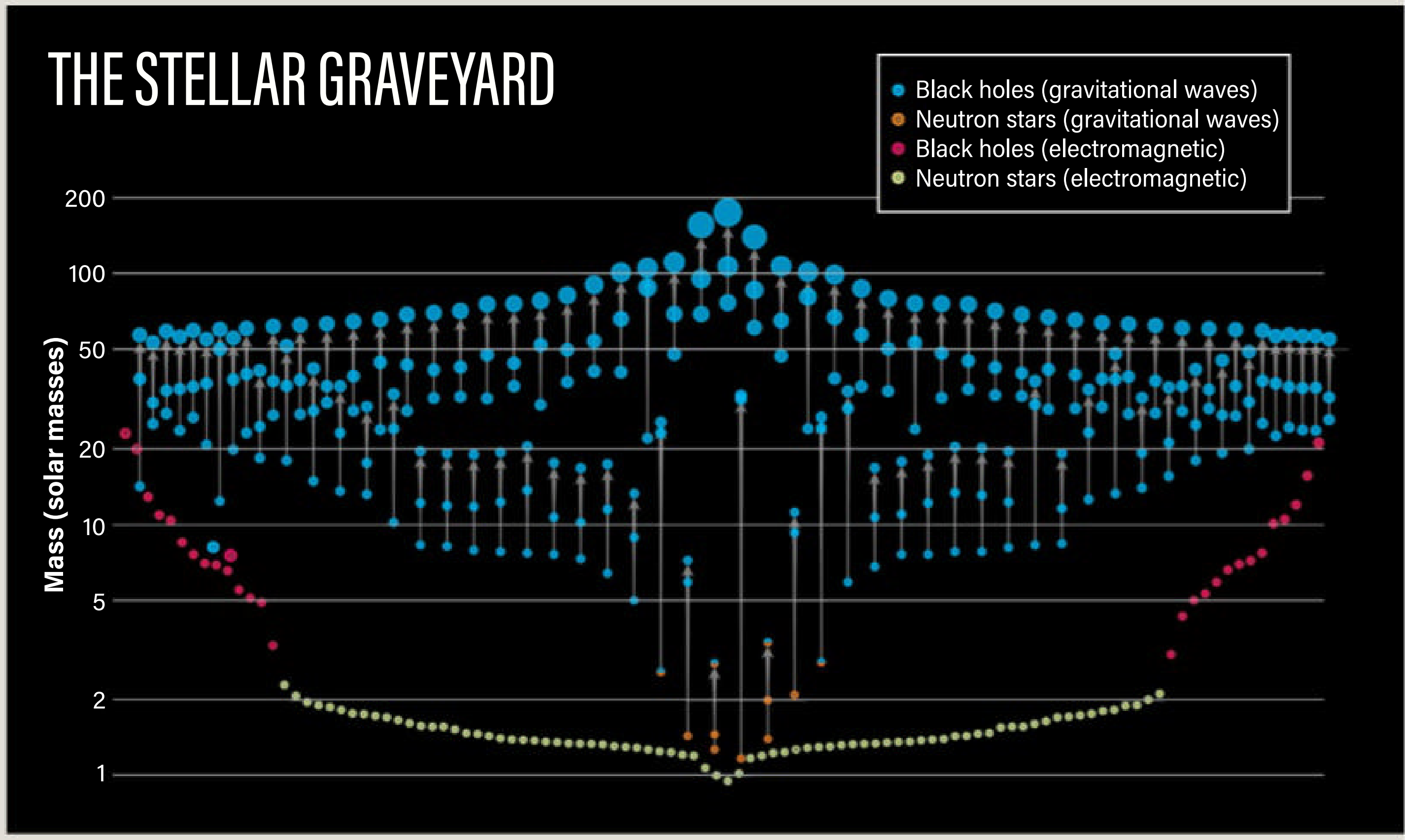
That's especially important because some astronomers think the ones found in binary systems may represent a biased sample. Their masses only range from about five to 20 times the Sun's mass, with most (including the newly discovered rogue black hole) weighing in at around 7 solar masses. But the true range may be much broader.

"Stellar-mass black holes that have been detected in other galaxies via gravitational waves are often far larger than those we've found in our galaxy — up to nearly 100 solar masses," Sahu says. "By finding more that are isolated, we'll be better able to understand what the true black hole population is like and learn even more about the ghosts that haunt our galaxy."

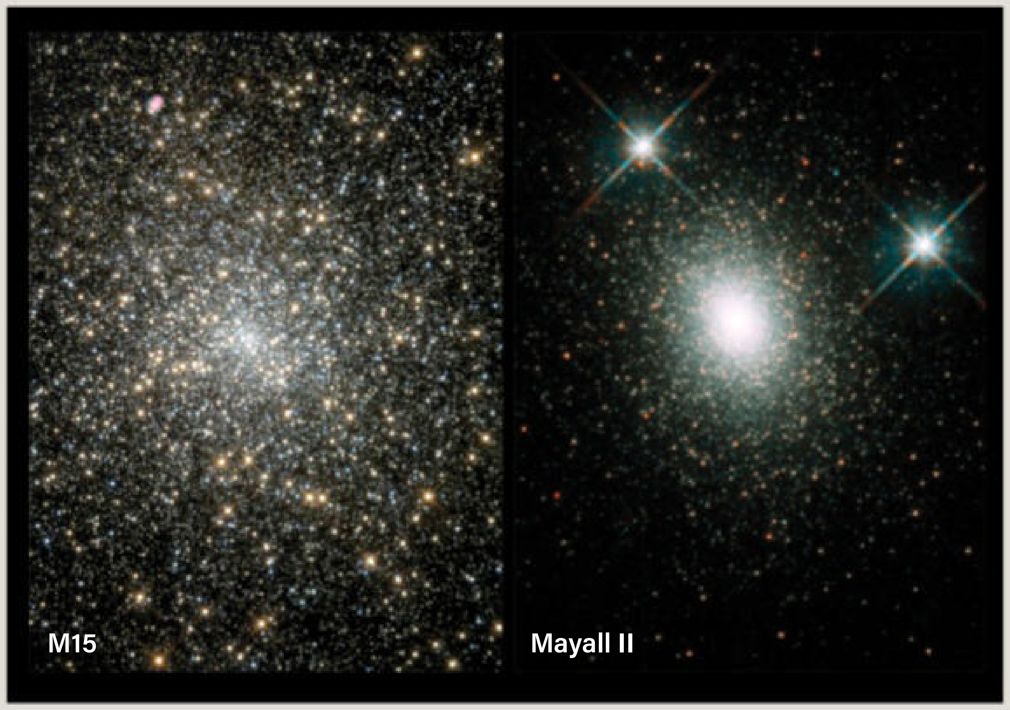
Dark secrets

In addition to studying rogue stellar-mass black holes, astronomers are also trying to piece together the history of their more massive counterparts, with consequences for the history of the universe.

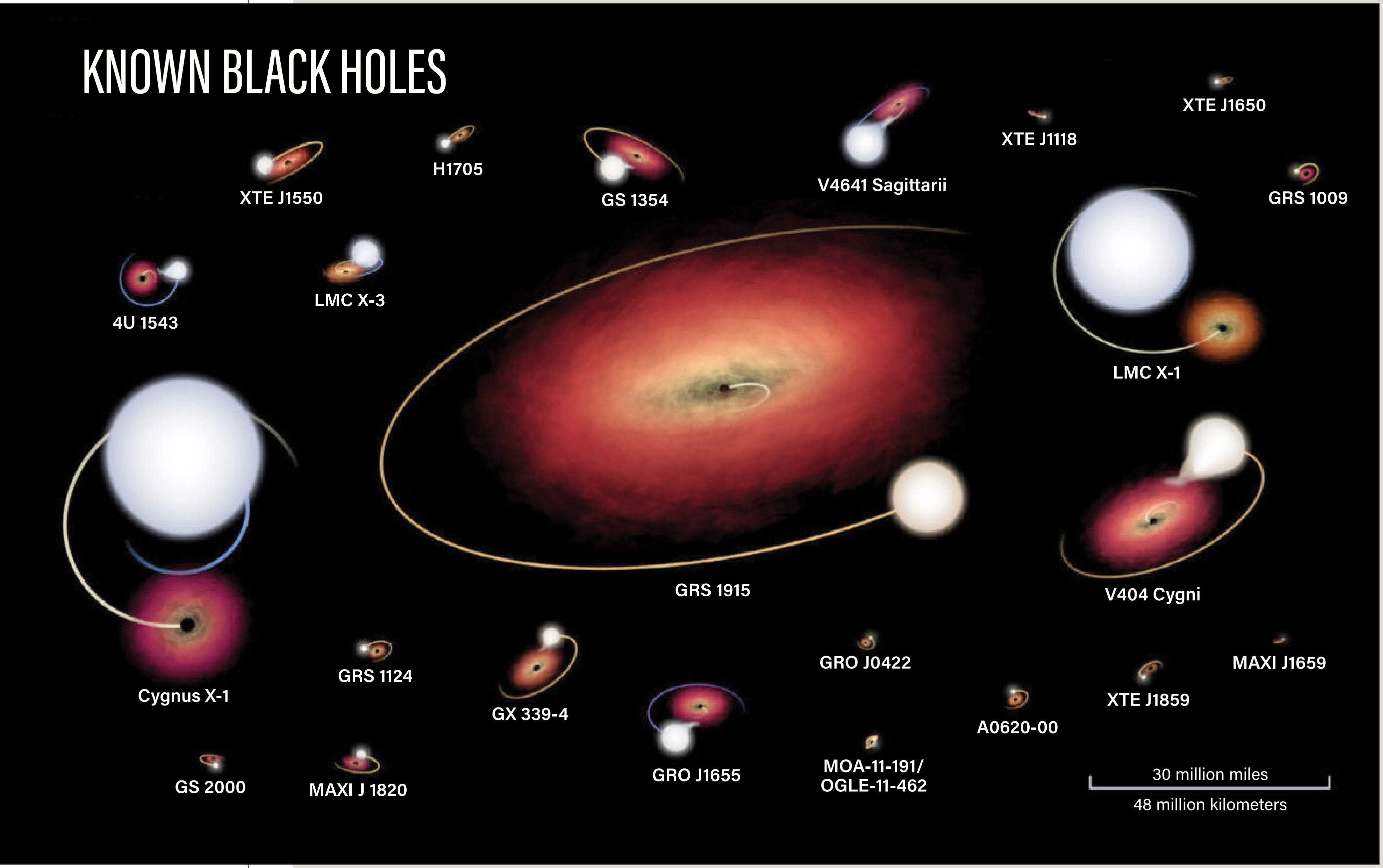
We've learned that nearly every galaxy in the cosmos hosts a supermassive black hole at its center. In the early universe, some of these behemoths released torrents of high-energy light as they gobbled



THE MASSES of all the black holes (blue, pink) and neutron stars (orange, yellow) detected via gravitational waves and electromagnetic observations as of 2021 are displayed here. At the highest-mass end are the few intermediate-mass black holes so far found. Arrows link the two progenitors and end product of each merger, from bottom to top. (Note that this is a graphic, not a graph — there is no x-axis, and the data have been laid out to be visually pleasing as well as informative.). LIGO-VIRGO/AARON GELLER/NORTHWESTERN UNIVERSITY



THE MASSIVE globular clusters M15 and Mayall II appear to host intermediate-mass black holes thousands of times the mass of the Sun at their centers, perhaps hinting at how such black holes form and grow. NASA/ESA, THE HUBBLE HERITAGE TEAM (STSCI/AURA) AND MICHAEL RICH (UCLA)



OF THE 23 KNOWN stellar-mass black holes in the Milky Way and Large Magellanic Cloud all but one (the newly discovered rogue, MOA-11-191/OGLE-11-462) are in a binary system with a companion star. This provides the black hole with a source of material to form an accretion disk that glows in X-rays. All systems are illustrated here at the same scale, though the black holes are represented by spheres larger than their actual size, scaled to reflect their mass. NASA'S GODDARD SPACE FLIGHT CENTER AND SCIENTIFIC VISUALIZATION STUDIO. MOA-11-191/OGLE-11-462: *ASTRONOMY*: ROEN KELLY, AFTER T. MÜLLER (MPIA)/ESA/GAIA/DPAC, CC BY-SA 3.0 IGO

up surrounding material. Astronomers have detected more than 100,000 of these objects, called quasars — but these exist only in the distant past, mostly 2 billion to 3 billion years after the Big Bang. There are none in our local (modern-day) universe. Thus, quasars appear to be a phase supermassive black holes go through early in a galaxy's life, feasting voraciously for a short time until they exhaust the available food supply as the galaxy settles down.

This brief period dramatically affects the evolution of a galaxy. Jets from a quasar can shut down star formation in its host galaxy, either by completely blowing away material that would have formed stars or by heating any gas that's left (star formation requires extremely cold temperatures to kick off). But astronomers have yet to unravel the details. "We know that a supermassive black hole can play a major role in shaping its galaxy's properties, like the birth rate of new stars," says Kristina Nyland, a radio astronomer at the Naval Research Laboratory in Washington, D.C. "But we don't understand how that connection has changed over cosmic time, or even how this type of black hole originated in the early universe."

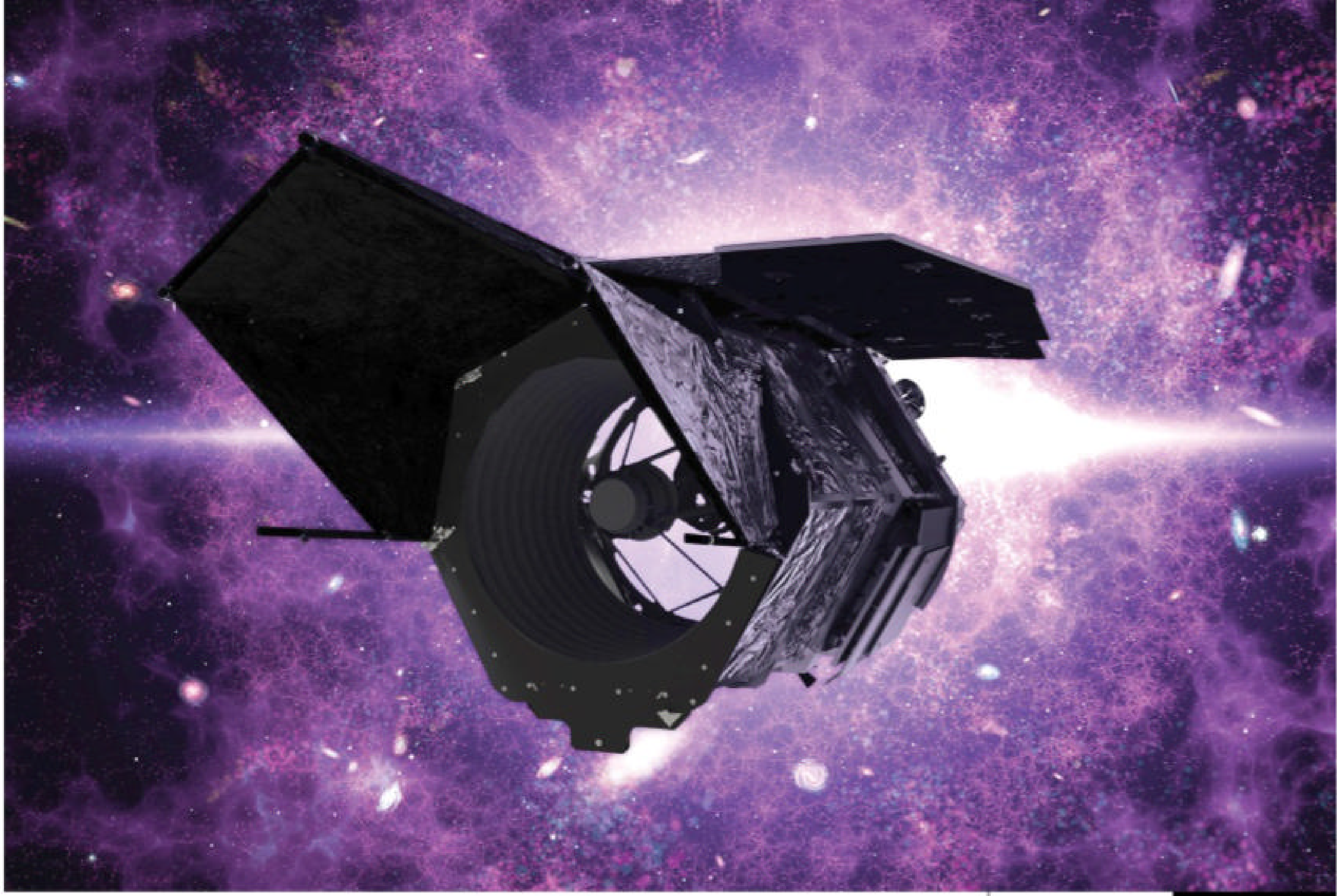
The fundamental mystery surrounding the origins of supermassive black holes is which came first — the supermassive black hole or its host galaxy.

One theory suggests that supermassive black holes formed right alongside their galaxies. As the material that filled the universe began to clump up, the lumpiest parts could have collapsed directly into black holes rather than myriad new stars.

But according to another theory, the heaviest black holes started out as lots of smaller ones. In this scenario, stars packed close together in clusters collided to form extremely massive stars, which ultimately collapsed and became intermediate-mass black holes (a variety that falls anywhere between the stellar-mass and supermassive ones). The clusters, now full of both stars and midsize black holes, would have fallen toward the center of the galaxy and merged to generate ever-larger black holes.

Right now, it isn't clear which formation pathway is correct. "It could be that there are multiple ways to build a supermassive black hole," Nyland says.

Much of the uncertainty stems from the fact that so far, astronomers have only identified a handful of intermediate-mass black hole candidates. Although astronomers



NASA'S NANCY GRACE ROMAN Space Telescope will conduct a survey for microlensing events in the galactic center. Astronomers expect it will find not only planets via this method, but also more rogue black holes like the one Sahu's team spotted. GSFC/SVS

think they may be common near the centers of dense star clusters or small galaxies, their gravity isn't strong enough to influence the way nearby stars move as dramatically as supermassive black holes do.

Instead, astronomers have largely had to rely on detecting ripples in the fabric of space-time when intermediate-mass black holes form. The first unambiguous detection came just in 2019: The Laser Interferometer Gravitational-wave Observatory (LIGO) and Virgo interferometer both picked up gravitational waves created when two distant black holes, weighing 85 and 66 solar masses, smashed into each other. The resulting black hole was 142 times the mass of our Sun, placing it squarely in intermediate-mass territory.

Unfortunately, based on the lack of gravitational-wave detections of intermediate-mass black holes since, they don't seem to be found in binary systems very often, unlike nearly all the stellar-mass black holes discovered so far. And relying on gravitational waves has another disadvantage: These ripples are affected by distance. The farther we are from the source, the weaker the signal we'll receive. That means any sample of black holes we have is biased toward nearby sources, and some mergers are altogether undetectable.

By the late 2030s, astronomers hope to be making even more gravitational-wave measurements. The European Space Agency is leading the Laser Interferometer Space Antenna (LISA) mission, a trio of spacecraft that will orbit the Sun 1.6 million miles (2.5 million km) apart. This incredibly long baseline will allow astronomers to study black holes in ways that ground-based interferometers can't, by detecting gravitational waves with wavelengths too large (i.e., frequencies too low) for Earth-based observatories to pick up. This includes gravitational waves from the mergers of intermediate-mass black holes. (LISA will also see events such as two supermassive black holes merging, as well as instances where a stellar-mass black hole spirals into a supermassive black hole.)

Black hole PLANETS

AMONG THE OBJECTS that NASA expects its powerful Nancy Grace Roman Space Telescope to reveal are not only rogue black holes, but maybe even planets orbiting black holes.

"The first exoplanets were discovered around a neutron star," says Jeremy Schnittman, an astrophysicist at NASA's Goddard Space Flight Center in Greenbelt, Maryland. "So why not black holes? I think the most likely case would be a binary system made up of a black hole and a 'normal' star companion, and then planets orbiting around either the black hole, the star, or both." If such a system exists, he says, "detecting it would be relatively simple, just like detecting and studying exoplanets transiting in front of their host stars, which we have done for thousands of systems already." *—A.B.V.*

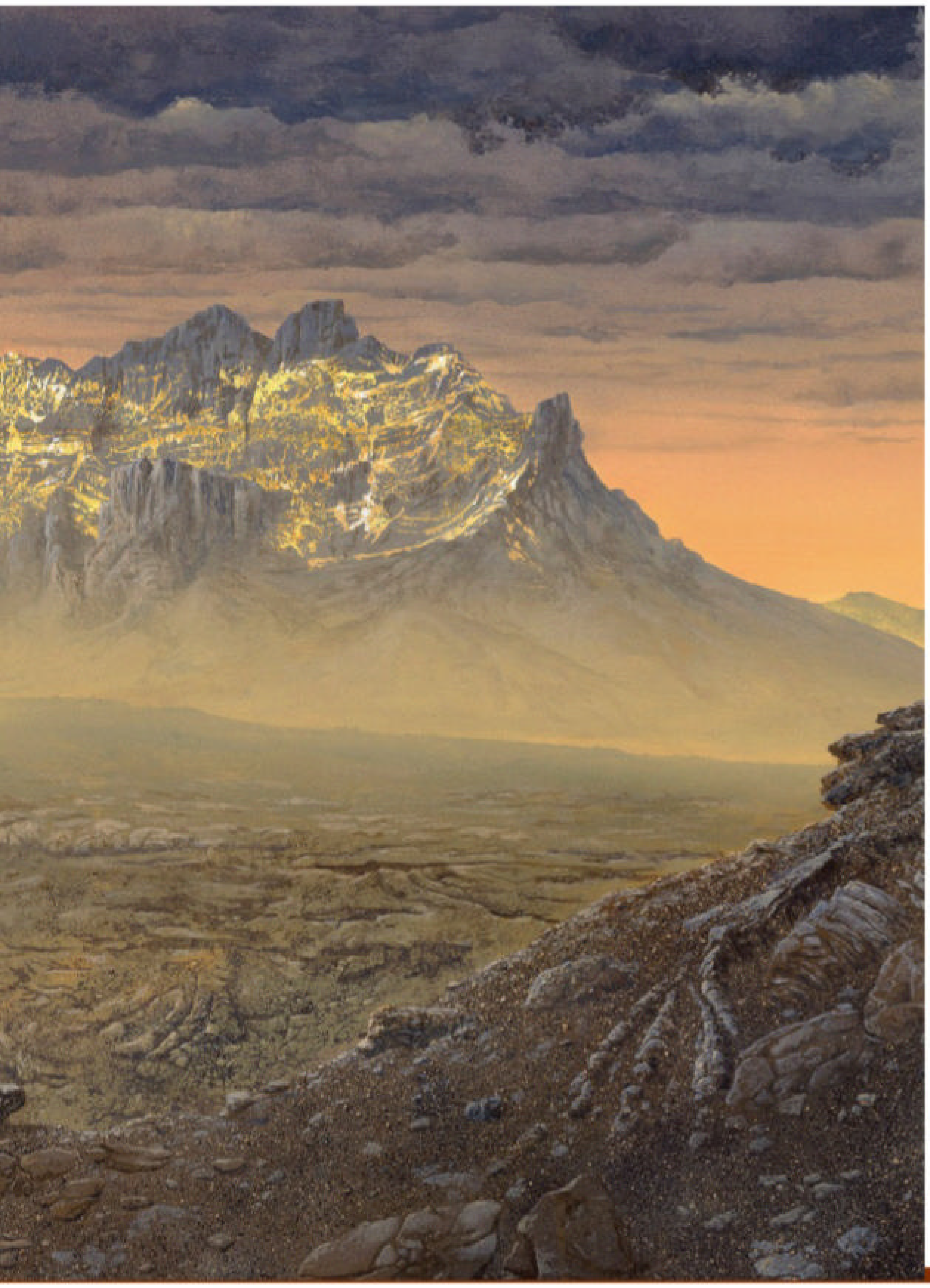
The key to solving many of the mysteries surrounding black holes may lie in multi-messenger astronomy, which pairs different types of observations, such as light and gravitational waves. Such data reveal far more than we could learn from any single type of observation, giving us a more complete picture of celestial objects and phenomena by looking at how they behave in more ways than just how they give off — or affect — light.

"As is so often the case when it comes to science, the more we learn, the more questions we seem to have," Sahu says. "There's no single discovery that's going to clear up all the open questions we have surrounding black holes, but each small finding we make will move us that much closer to understanding the underpinnings of this beautiful universe we live in."

Ashley Balzer Vigil *is a science writer for a contractor at the NASA Goddard Space Flight Center. Her work focuses on bringing exciting astrophysics discoveries to the public.*

Revealing VENUS

Earth's sister world does not give up its secrets easily to visiting spacecraft. BY MICHAEL CARROLL



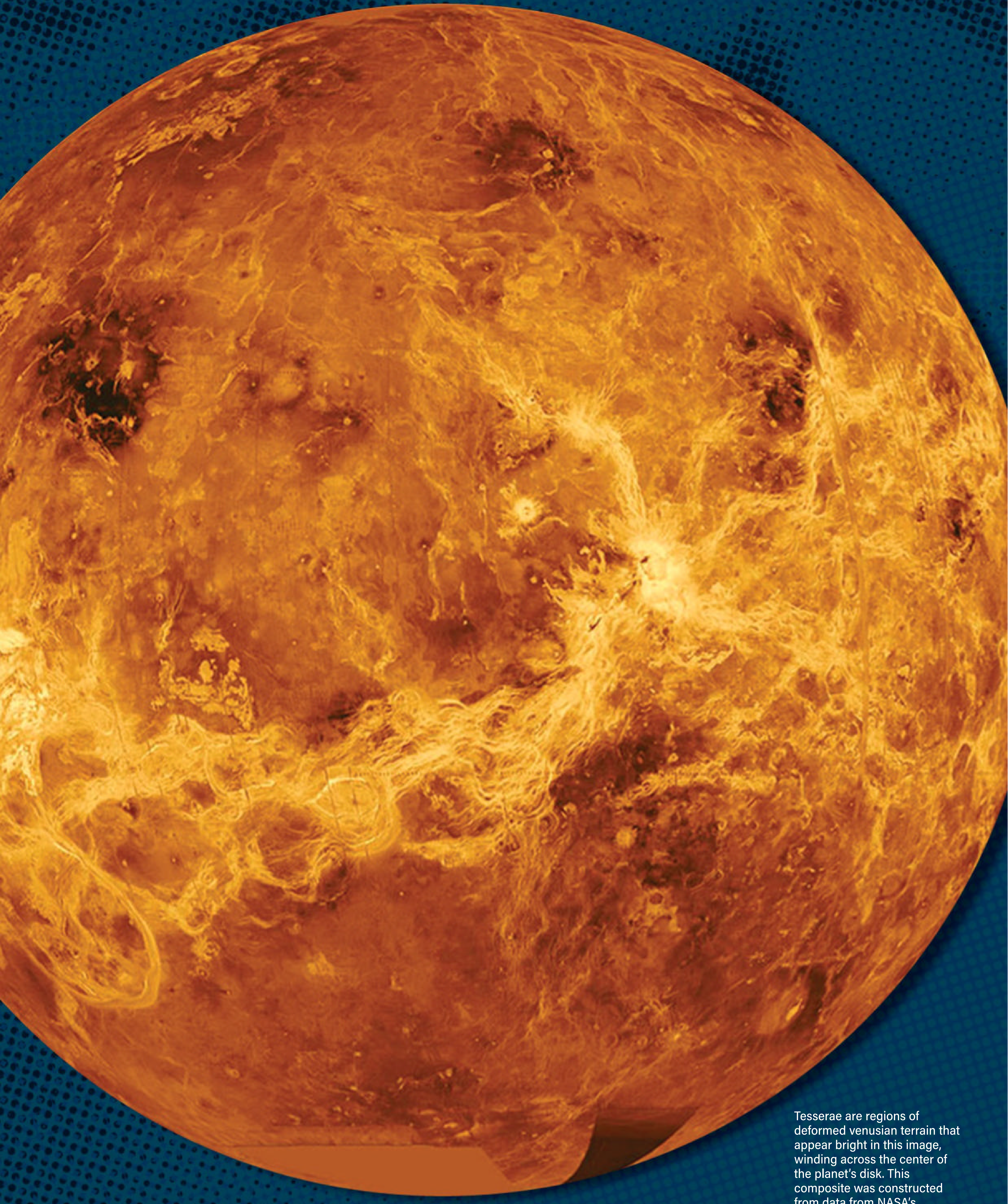
Iron pyrite, also known as fool's gold, tops the peak of Akna Montes like fallen snow in this painting by the author. MICHAEL CARROLL

If the exploration of the planets has taught us one thing, it is that Murphy's law — "anything that can go wrong will go wrong" — is alive and well throughout the solar system. But one planet in particular exhibits more than its share of quirks: Venus.

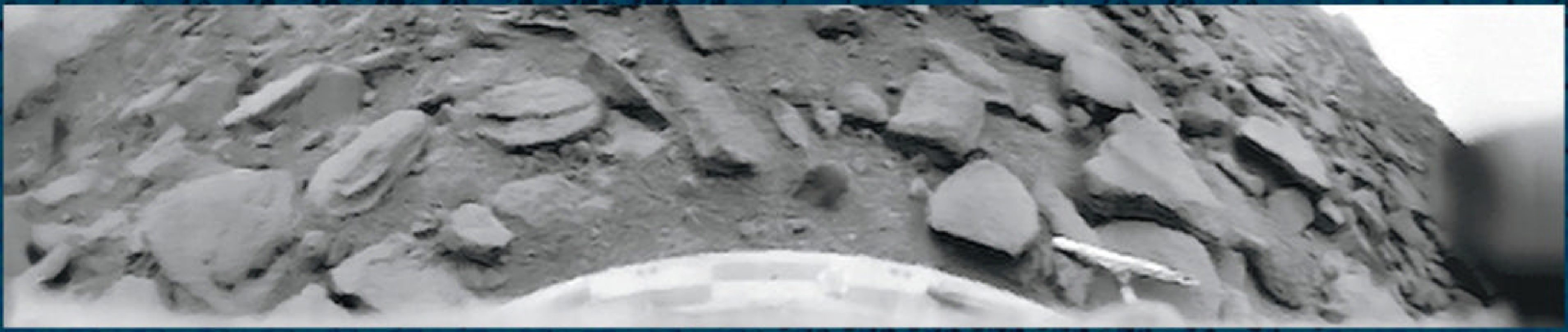
It's no wonder. Venus is a tough place to study, let alone land on. The planet's toxic environment is seasoned with sulfuric acid and pressurized at the surface to 90 times the crush at Earth's sea level, or roughly equal to that of an ocean depth of 3,000 feet (900 meters). Temperatures soar to 900 degrees Fahrenheit (482 degrees Celsius). And every four days, an atmospheric tsunami sends a front of hurricane-force winds around the globe.

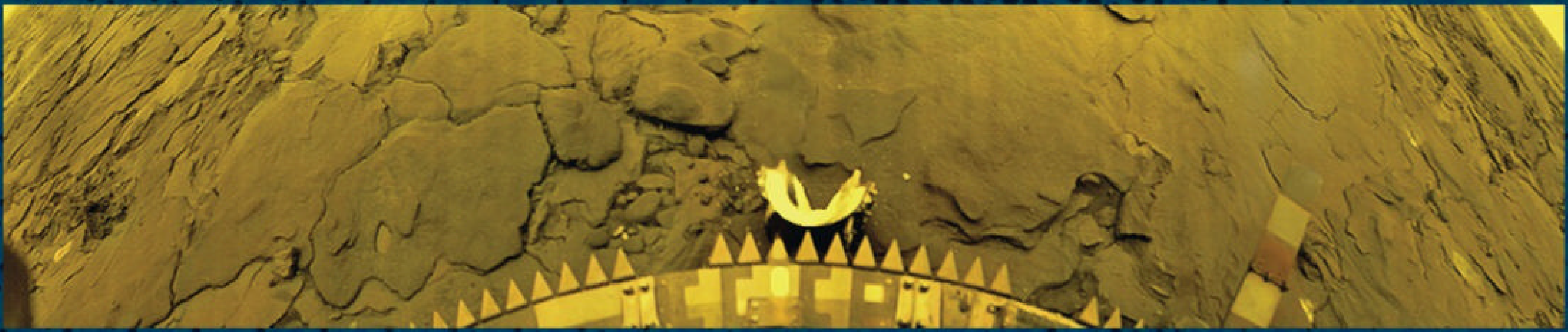
Despite those obvious challenges, the spacecraft that have dared to land on Venus' brutal plains have revealed a planet much more complex and fascinating. Although Venus is closer to the Sun than Earth by a third, that alone cannot explain the dramatic differences between our two worlds. And Venus' massive ocean of air and extraordinary environment are critical to our understanding of issues like climate change and extreme weather on Earth.

Despite Murphy's law — or perhaps because of it — scientists are getting closer to understanding what makes Earth's sibling planet tick.



Tesserae are regions of deformed venusian terrain that appear bright in this image, winding across the center of the planet's disk. This composite was constructed from data from NASA's Magellan and Pioneer Venus Orbiter missions. NASA/JPL-CALTECH





TOP: In 1975, the Soviet Venera 9 mission returned the first images from the surface of another planet.

ABOVE: The Venera 14 craft, which landed on Venus in 1982, was unfortunate to have its lens cap land right beneath the arm that was supposed to take data on the soil. RUSSIAN ACADEMY OF SCIENCES/TED STRYK

LEFT: Although Venera 14's panoramic cameras were mostly aimed at the nearby ground, this reconstruction offers a realistic view of what the surrounding terrain would look like. SOVIET PLANETARY EXPLORATION PROGRAM, VENERA 14; PROCESSING AND COPYRIGHT: DONALD MITCHELL & MICHAEL CARROLL

Water, water everywhere?

The first probe to fly by Venus was Mariner 2, in 1962. The scorching atmospheric temperatures it found confirmed that the planet had been the victim of a runaway greenhouse effect. But in 1978, NASA's Pioneer Venus Multiprobe mission found evidence for something that seemed unbelievable: The desiccated, desolate planet may once have had oceans washing across its ancient face.

The groundbreaking discovery was unplanned. As the large probe deployed by the main spacecraft descended through the venusian atmosphere, a cloud droplet clogged the intake of an instrument. Although the droplet prevented many readings of the environment over the rest of the descent, researchers were able to carefully chart the makeup of the droplet itself.

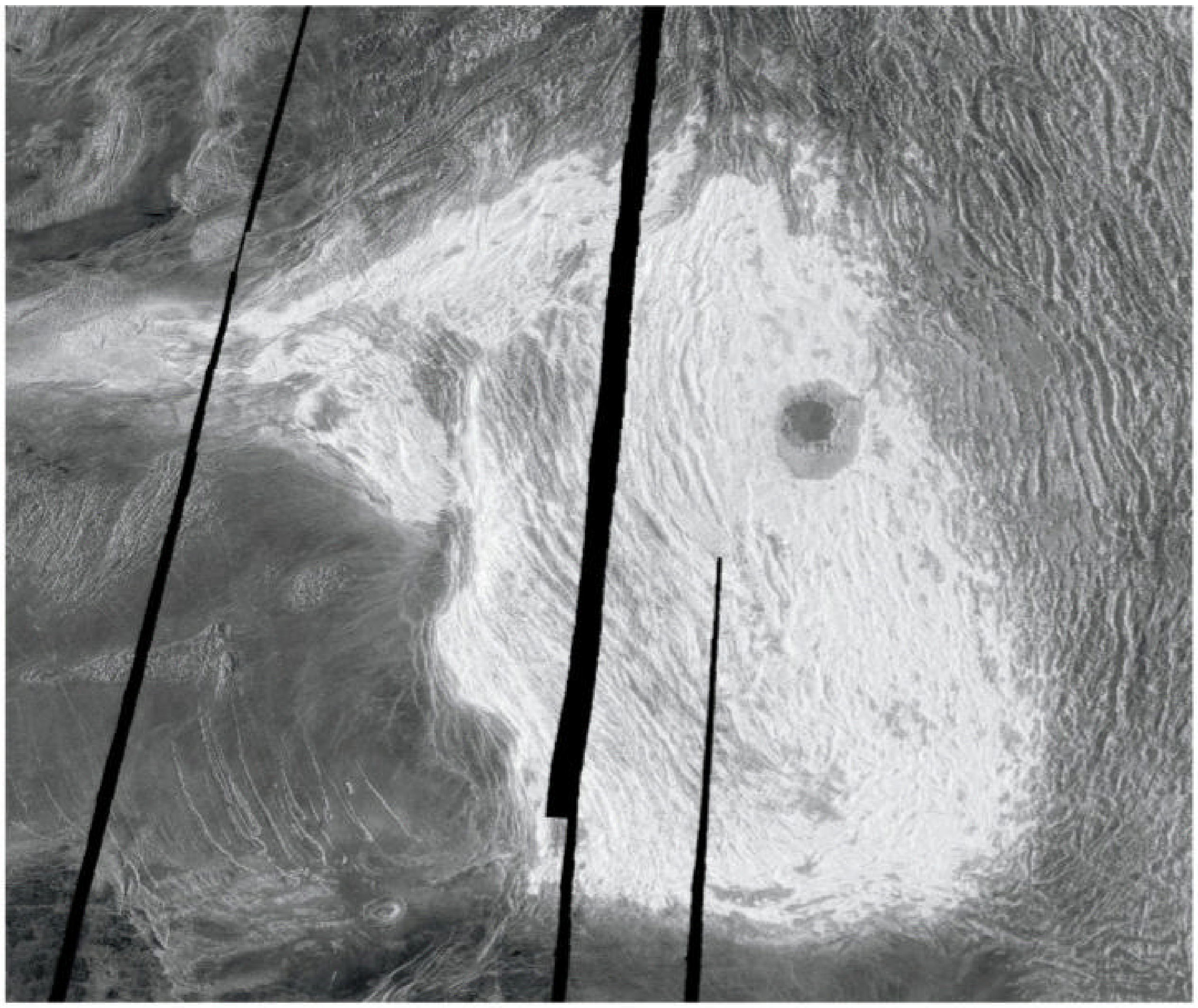
They found it was rich with deuterium — an isotope of hydrogen with an extra neutron. Deuterium is somewhat rare, with about 1 for every 6,500 normal hydrogen atoms on Earth. That ratio tells scientists about the history of that hydrogen. On Venus, deuterium is about 100 times more prevalent than on Earth. This indicates to some researchers that Venus must have once had vastly more hydrogen — most likely in the form of water, and oceans of it. As solar radiation blasted Venus over eons, the lighter, regular hydrogen drifted off into space, leaving behind an overabundance of deuterium.

Venus and Earth arose near each other within the Sun's formative solar nebula. The two worlds must have come from roughly the same building blocks. As astrobiologist David Grinspoon of the Planetary Science Institute in Tucson, Arizona, wrote in the book *Alien Seas* (Springer, 2013), "Unless some tremendously efficient process dried Venus out completely, it must have started with more water, perhaps even an Earth's ocean's worth of water — perhaps 10 times this much."

Additional evidence for oceans came from the Soviet Venera 8 lander, which touched down on Navka Planitia in 1972. The spacecraft carried a gamma-ray spectrometer that took measurements of the air during descent, along with two precious-mineral readings from the surface. The instrument detected potassium, uranium, and thorium — a cocktail of elements also found in granite. Infrared imagery from subsequent missions has yielded hints of granite mountains, as well. Granite forms in the presence of water, making this a possible sign of long-gone ancient seas in a more temperate era.

Over the rest of the decade and into the

Venus and Earth arose near each other within the solar nebula. The worlds must have come from roughly the same building blocks.



Maxwell Montes is the highest mountain on Venus, at roughly 36,000 feet (11,000 m). Radar imagery from Magellan shows a distinct snow line that is about 11,500 feet (3,500 m) higher on the mountain's northwest flanks than in its southeastern area. Evidently, winds from the southeast carry metallic vapor up the slopes and deposit it as snow, creating a snow shadow on the northwest side of the mountain. NASA/JPL

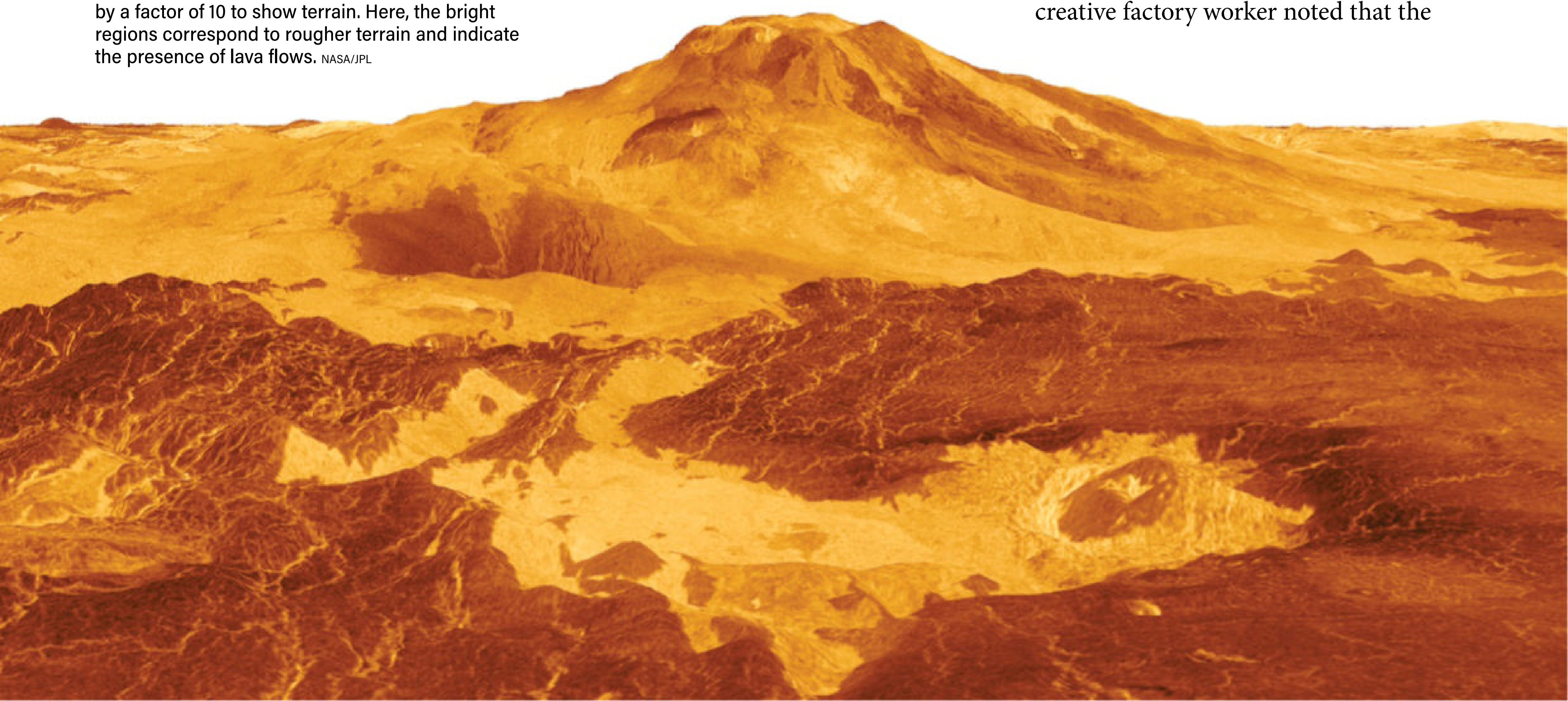
mid-1980s, the Soviet Union's Space Research Institute sent an armada of landers and orbiters to further explore this possibility. Many of these probes saw Murphy's law raise its fickle head.

The Venera 9 and 10 landers incorporated design improvements over earlier spacecraft, but in both cases, their lens caps jammed on one camera. (Both carried a rear and front camera system, so they were still able to transmit the first dramatic images from the surface of another planet.) Engineers crafted new seals for the cameras on Venera 11 and 12. The seals worked too well: All the camera covers jammed on, so the twin landers returned no images. It turned out that the air pressure outside was higher than that inside the sealed cameras, so the pressure difference simply held the caps in place. Later designs had better venting, allowing for spectacular full-color 360° vistas.

But even properly working lens caps caused mishaps. After landing on an enchanting landscape of broken fine-grained, layered stone, Venera 14's lens caps successfully ejected. The rear panoramic camera saw its cap resting atop plates of interlocking rock. But in the front view, the cap seemed to have vanished. Then shocked flight engineers spotted it, lying directly beneath the spring-loaded arm that was to probe the soil's firmness. With no ability to rearticulate the arm, Venera 14 suffered the indignity of traversing the inner solar system only to measure its own lens cap!

Sometimes humans contributed some bad luck of their own. During the design of the Venera 13 and 14 color cameras, Soviet researchers developed advanced paints that could retain their color even in the 900 F (482 C) heat. These would be placed in the camera's field of view to calibrate the color images. In those days, the Soviet system was divided into two departments: the engineers who researched and designed the mission, and a different ministry that fabricated the hardware. The latter's industrial plants had "suggestion boxes" where workers were encouraged to make suggestions about ongoing projects. One creative factory worker noted that the

Some scientists think Maat Mons, rendered here with NASA Magellan radar data, is an active volcano. The elevation has been exaggerated by a factor of 10 to show terrain. Here, the bright regions correspond to rougher terrain and indicate the presence of lava flows. NASA/JPL



ministry was paying incredible amounts for exotic paint chips when cheaper paint was readily available. Commercial paint was substituted and the worker was rewarded for their contribution. Sadly — as the engineers predicted — the paint immediately lost its color in the furnace-like venusian conditions.

An atmospheric anomaly

Perhaps the most intriguing instances of Murphy's law befell both U.S. and Soviet probes. NASA researchers called it the Pioneer Venus 12.5-kilometer anomaly: a strange occurrence that afflicted the four probes in the Pioneer Venus Multiprobe armada as they simultaneously descended through Venus' complex atmosphere. At an altitude of about 7.5 miles (12.5 km), below the planet's known cloud decks, a power spike surged through all four probes, even though they were thousands of miles from each other, some in daylight and some in regions experiencing night. This resulted in bizarre readings of temperature and pressure. Many instruments failed completely, losing valuable data. What was going on within those battery-acid clouds?

Some engineers say the power spikes were due to the hardware design of the Pioneer probes themselves. A 1993 NASA report found that "[a]ll anomalous events are now explained" by a failure of insulation material. Protective Kapton tape had been tested in chambers simulating Venus conditions and deemed adequate for the wiring on the probes' external sensors. But technicians decided to reinforce the external connections by using Kynar, a type of shrink tubing not tested in the same manner as the Kapton had been. When this tubing reached 620 F (327 C), it could have released corrosive hydrogen fluoride vapors that dissolved the Kapton insulation, shorting out the connections.

However, a hardware failure common to the Pioneer probes doesn't explain all aspects of the phenomenon. "What's puzzling is that different spacecraft had the same anomalies," says Grinspoon. Soviet probes Venera 11, 12, 13, and 14 all experienced similar power spikes at about the same altitude. And years later, the Vega 1 Venus lander may have prematurely triggered its landing sequence when its sensors indicated that it had landed — some 11 miles (18 km) above the surface. Vega 1 dutifully drilled and sampled, but there were no rocks up there to test. (Strangely, the sister craft, Vega 2, had no ill effects at similar altitudes.)

In 1995, three Washington University geochemists proposed a different possibility for the Pioneer Venus anomaly: metallic fog in the highlands. Evidence for this weather phenomenon came from radar imaging of the planet, which revealed a strange pattern of brightening on high ground. In radar imagery, bright reflections usually mean a rough surface, but on Venus this shimmering veneer blankets everything from craggy mountains to high plateaus.

To explain this, the team noted that on Venus, as on Earth, temperatures drop with altitude. Low-lying plains on Venus simmer at a blistering 872 F (467 C), while the radiant higher elevations cool down to a lovely 728 F (387 C). And at Venus' drastic pressures, certain metals that can exist as vapor in the lowlands could migrate to higher terrain, condense as they cool, and even accumulate on the ground as "snow."

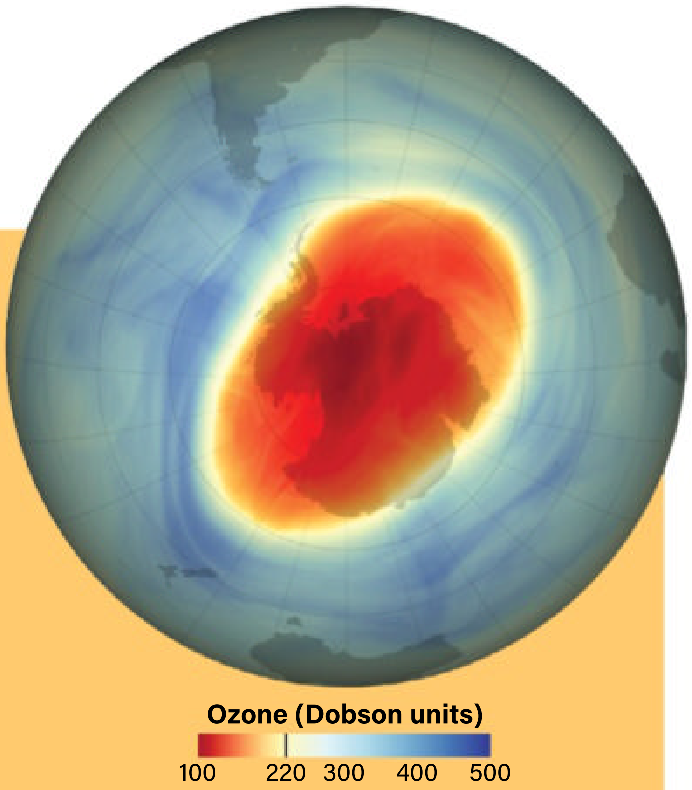
A variety of metals could be involved, including chlorine, fluorine, and sulfur. Other intriguing candidates include lead sulfide, bismuth, the chromelike metal tellurium, and iron pyrite (fool's gold). These metals also appear to condense at

How Venus saved our skin

IN THE EARLY 1970S, scientists were seeking to understand the dominance of carbon dioxide in the venusian atmosphere. Through this work, planetary scientists like Harvard University's Michael McElroy became aware of the importance of catalytic reactions involving chemicals like chlorine in Venus' atmosphere, which reacts with and breaks down ozone. In April 1974, McElroy co-authored a paper warning that the chlorine emitted in the rocket exhaust of NASA's upcoming space shuttle could threaten Earth's ozone layer, which shields us from harmful ultraviolet radiation.

Just two months later, a pair of chemists at the University of California, Irvine, Mario Molina and Sherwood Rowland, independently identified a much bigger source of chlorine: chlorofluorocarbons (CFCs), which were widely used in industry as refrigerants, insecticides, spray can propellant, and more. Their work was published in *Nature*.

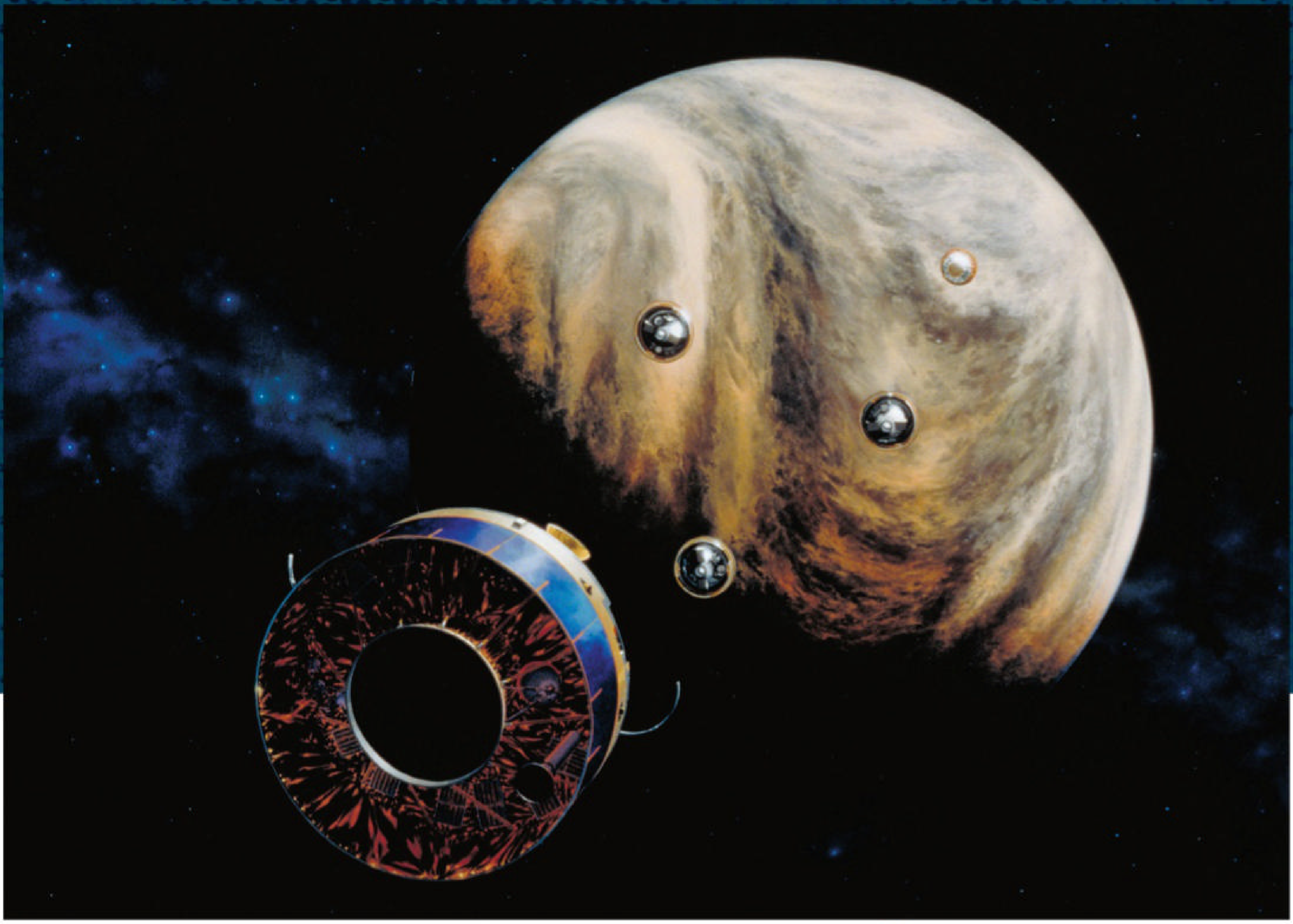
At ground level, CFCs are stable and nontoxic. But as they drift higher into Earth's atmosphere, the Sun's ultraviolet rays break them down and the resulting chlorine destroys ozone through catalytic reactions — the same process that McElroy's group had identified on Venus. Using atmospheric-mixing models that McElroy and his colleagues had developed for Venus, Molina and Rowland concluded that these chemicals could last for up to 150 years.



The size of the ozone hole over Antarctica peaked in 2006 but has slowly recovered thanks to the landmark 1987 Montreal Protocol, which limited CFC emissions. The maximum extent of the hole in 2022, mapped here on Oct. 5, was slightly smaller than the year before. The scale is given in Dobson units, which correspond to the equivalent thickness of the ozone layer in hundredths of a millimeter if it were isolated at 32 F (0 C) and 1 atmosphere of pressure. NASA EARTH OBSERVATORY IMAGE BY JOSHUA STEVENS

We had unknowingly set the stage for turning Earth into a hot zone of skin cancer and damaged crops. The result was the Antarctic ozone hole, which was discovered by British researchers in 1985.

The good news is that governments and industry took action to reduce the use of CFCs worldwide and the ozone hole is now shrinking. A January 2023 report from the U.N. found Antarctic ozone levels are expected to recover to 1980 levels by 2066. *— M.C.*



The Pioneer Venus Multiprobe spacecraft (lower left) released four probes, shown in this illustration. The so-called large probe (far upper right) was roughly 5 feet (1.5 m) across; the other three were smaller and identical. The quartet descended into the planet's atmosphere Dec. 9, 1978. NASA/PAUL HUDSON

about the same altitude as the Pioneer Venus anomaly. If they condensed on the surfaces of all these probes, they could have triggered a host of breakdowns and temporary electrical failures — and would certainly qualify as another arrow in Murphy's quiver.

Tale of two worlds

Fortunately, answers to this and other mysteries may be at hand in the coming years. Researchers and space agencies are preparing a new wave of Venus missions slated for launch in the early 2030s. These include the European Space Agency's EnVision orbiter; NASA's VERITAS orbiter; and NASA's DAVINCI mission, which will consist of an orbiter and an atmospheric probe — the first craft to venture into the planet's clouds since the USSR's pair of Vega balloons in 1985. (VERITAS is an acronym for Venus Emissivity, Radio science, InSAR, Topography, And Spectroscopy; InSAR, or interferometric synthetic aperture radar, is a radar technique for mapping terrain. DAVINCI stands for Deep Atmosphere Venus Investigation of Noble gases, Chemistry, and Imaging.)

Sadly — as the engineers predicted — the paint immediately lost its color in the furnacelike Venusian conditions.

To make up for its capricious ways, Venus has bequeathed to humanity information critical for our own good. Scientists and policymakers have come to realize that Venus is an important mirror that can help us understand some deep truths about our own planet on issues ranging from global warming to the depletion of the ozone layer. It serves as a climate laboratory, an extreme-weather observatory, and a cautionary tale — a bleak example of what could happen to our fragile world. Through its inhospitality, Venus may help us to better manage Earth's resources and environment, and to avoid changing this temperate world into one more like that of our twin next door. Though Murphy's law may spare no spacecraft, it doesn't have to apply to our own planet.

Michael Carroll *is a science journalist and space artist. He has published over 30 books and is a founding member of the International Association of Astronomical Artists.*

SKY THIS MONTH

Visible to the naked eye
Visible with binoculars
Visible with a telescope

THE SOLAR SYSTEM'S CHANGING LANDSCAPE AS IT APPEARS IN EARTH'S SKY.

BY MARTIN RATCLIFFE AND ALISTER LING

In the middle of a penumbral lunar eclipse, one limb of our satellite will appear darker, creating a slight gradient across the Moon's face. GIUSEPPE DONATIELLO

MAY 2023

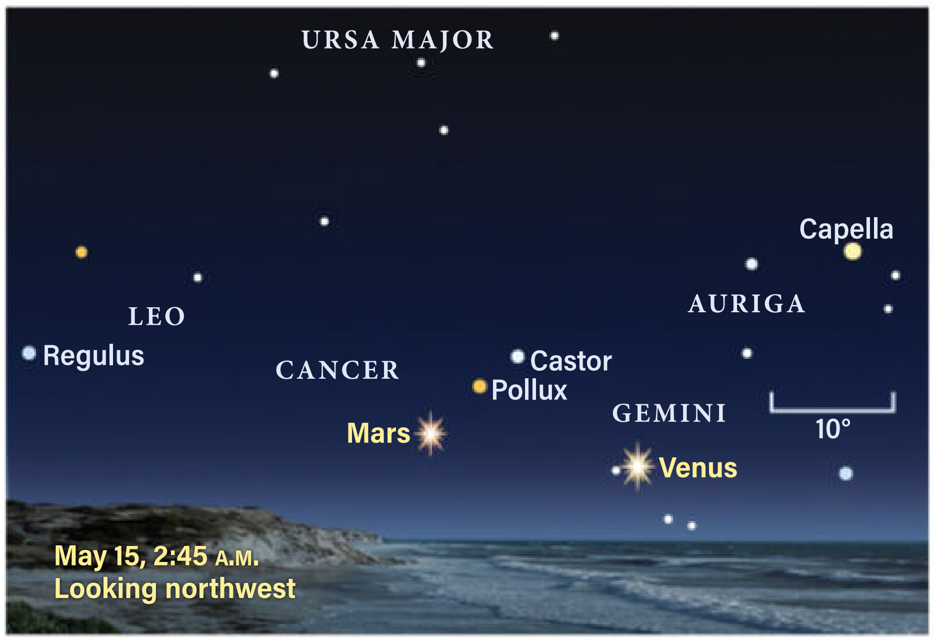
A dusky Moon

Venus puts on its best show of the year in the evening sky, visible until very late. Mars also continues as an evening object, while other planets congregate in the morning. Saturn is beginning to improve its visibility in the predawn sky and Jupiter, reappearing after solar conjunction, takes part in a spectacular twilight occultation by the Moon.

We start the monthly tour with **Venus** shining brilliantly in the western sky. It glows at magnitude –4.1 at the start of the month and brightens by three-tenths of a magnitude by May 31. You'll find it nicely placed between the horns of Taurus the Bull on the 1st.

Venus exits Taurus a week later and moves to a point north of Eta (η) and Mu (μ) Geminorum on May 9, when it achieves its maximum declination north (26°) and its farthest point above the ecliptic. A

In the north



During the long twilight in Alaska this month, Venus is situated north — an unusual location. This chart shows the early-morning view specifically from Anchorage. ALL ILLUSTRATIONS: *ASTRONOMY*: ROEN KELLY

OBSERVING HIGHLIGHT

THE MOON covers **JUPITER** in an occultation that takes place the morning of May 17.

telescope will show a gibbous disk 63 percent lit and 18" across.

This northerly extent places Venus in interesting parts of the sky for northern tiers of the U.S. and particularly in Canada and Alaska. Normally visible in the western sky after sunset, Venus is almost circumpolar for Anchorage, Alaska, and is visible at midnight in the northwestern sky. Shortly before 3 A.M. local time, Venus lies low on the northwestern horizon, an unusual placement for an inferior planet. During the long twilight, Venus remains situated north. From Fairbanks, Alaska, Venus lies due north at sunrise, sitting 1° above the horizon.

Venus continues across Gemini and ends the month south of Pollux, similar to the location of Mars early in the month. A telescope shows Venus close to half phase (dichotomy) on May 31, with a 52-percent-lit disk spanning 23".

Mars is 5° due south of Pollux on May 9. The Red Planet is magnitude 1.4; Pollux shines brighter at magnitude 1.2. Mars crosses into Cancer by May 17 and drifts closer to the famous Beehive Cluster (M44). A crescent Moon arrives 3° north of M44 on May 24, with Mars standing 5° west of the cluster.

— Continued on page 34

RISING MOON | Moon mounds

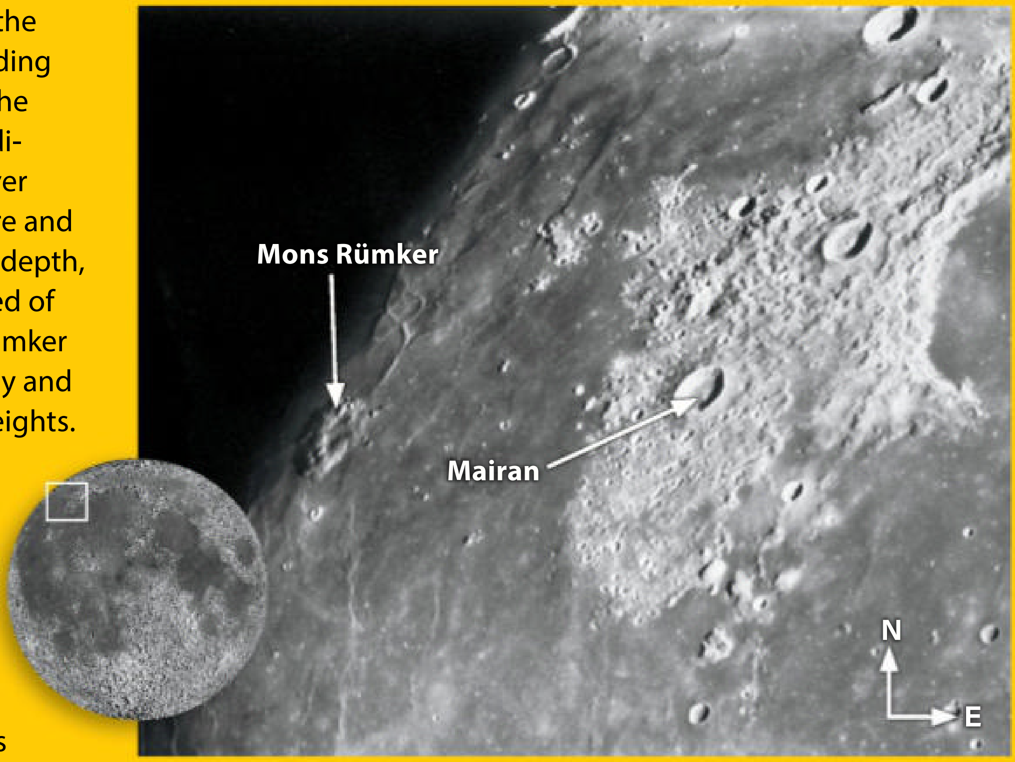
WHAT A SIGHT the Moon must have been 3 billion years ago: Lava surging from the lunar interior and spreading across huge basins! As the surface cooled and solidified, local upwellings over hot spots continued here and there. In contrast to the depth, violence, and superspeed of impact cratering, the Rümker hills rose relatively slowly and reached only modest heights.

A good look at this topographic mound means observing on the 2nd. Its unusual nature is eye-catching. The eastern flank just does not look like the rim of a walled crater. It's as if the Moon had hives that day.

The gentle hills cast long shadows under the rising Sun, but a mere 24 hours later, they have all but disappeared. We can't know for sure that the flat central part is a caldera, but it looks like the hole left from the collapse of the peak, which then flooded with magma. Rümker returns to visibility late on the 31st.

Locate the fascinating volcanic feature by starting at the brilliant Aristarchus, then slide north along the wrinkled terminator. The terrain around Aristarchus was also molded by long-lived flows of lava. There is so much to take in here! Farther south lie the volcanic domes near the crater Marius and the huge bowl of Schickard.

Mons Rümker



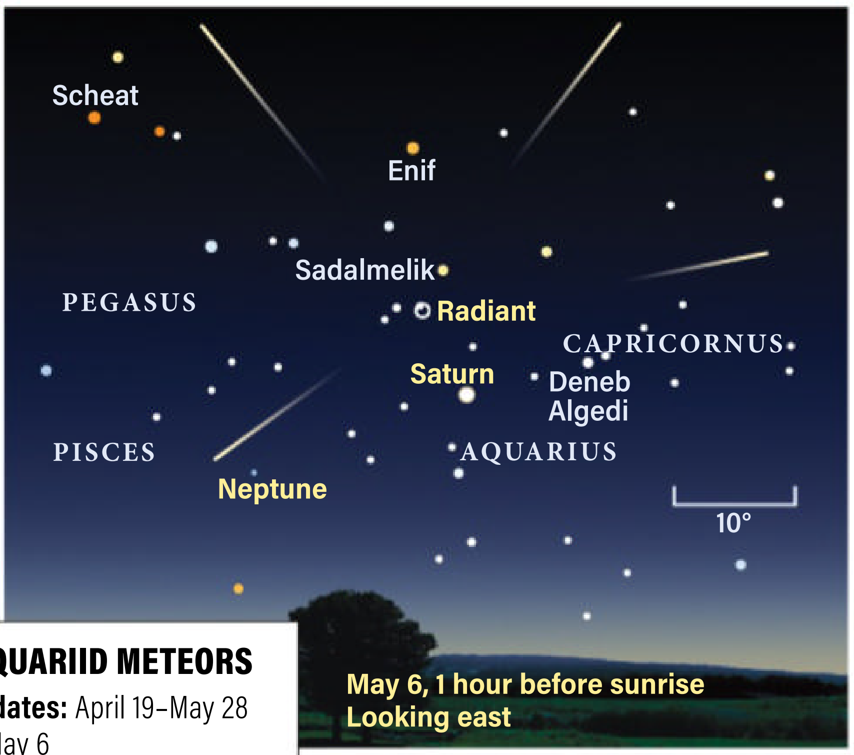
Mons Rümker is a striking volcanic feature north of Aristarchus and near the crater Mairan. CONSOLIDATED LUNAR ATLAS/UA/LPL. INSET: NASA/GSFC/ASU

METEOR WATCH | Halley's leftovers

THIS MONTH'S ETA AQUARIID SHOWER is active between April 19 and May 28, peaking on May 6. The peak of the meteor shower is heavily affected by the Full Moon (May 5), which remains visible all night. The typical zenithal hourly rate of 50 per hour on May 6 is severely reduced to a trickle, with only the brighter members observable. The low altitude of the radiant doesn't help, either. It rises just after 2 A.M. local time on the morning of maximum and reaches about 20° above the horizon as twilight breaks. Try observing during the first few of days of May to catch any early shower members after the Moon sets (4:30 A.M. on May 2).

The Eta Aquariids are one of two showers associated with Halley's Comet, whose dusty debris left over from hundreds of orbits also results in the October Orionids.

Eta Aquariid meteor shower

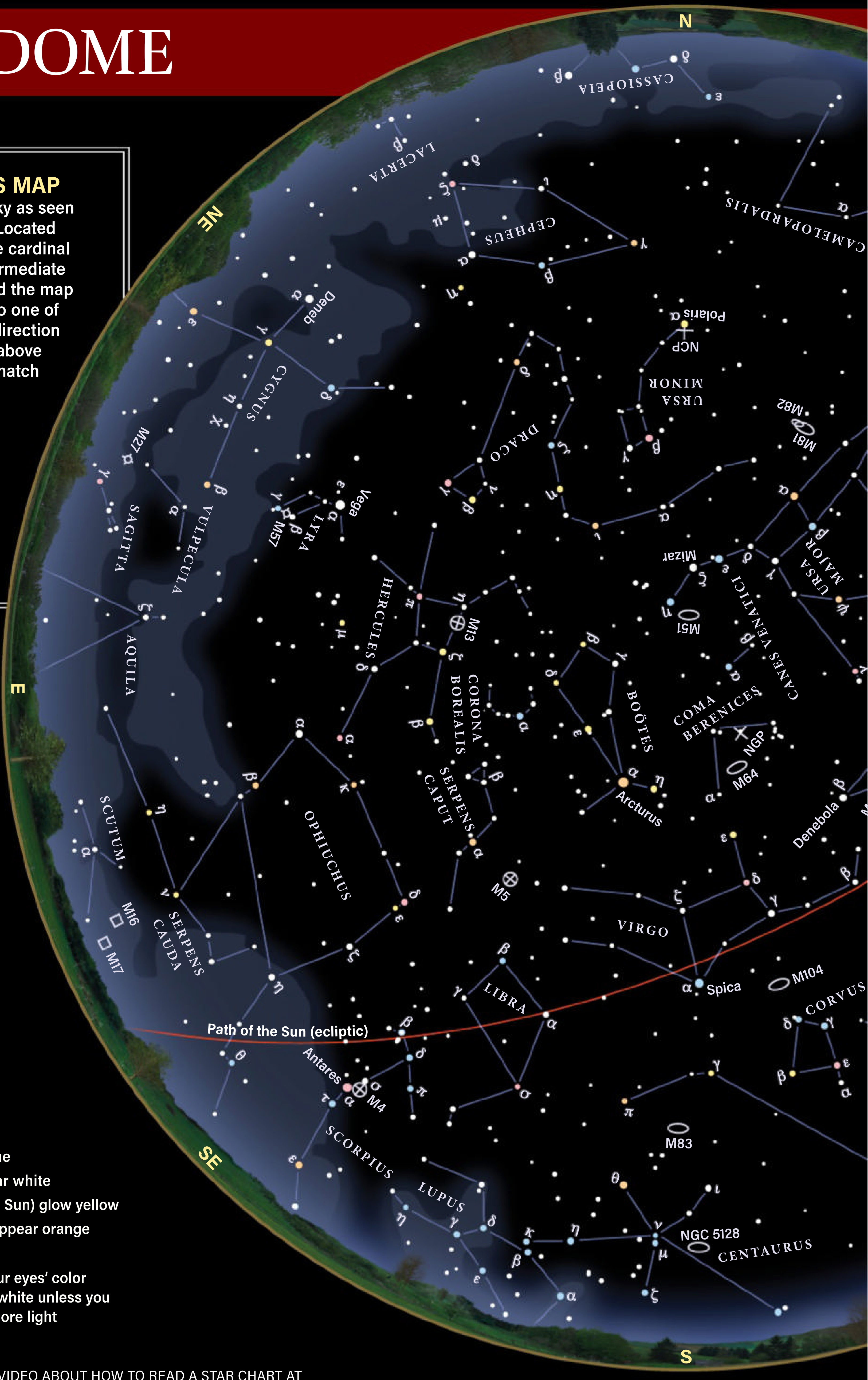


The Eta Aquariids' radiant is highest just before dawn. Try to catch it earlier than the peak date of May 6 to avoid the Full Moon.

ETA AQUARIID METEORS

Active dates: April 19–May 28
Peak: May 6
Moon at peak: Full
Maximum rate at peak:
50 meteors/hour

STAR DOME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SAGITTA
Vega
LYRA
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HERCULES
M13
CORONA BOREALIS
BOÖTES
Arcturus
AQUILA
SERPENS CAPUT
OPHIUCHUS
M5
VIRGO
Spica
M104
CORVUS
SCUTUM
M16
M17
SERPENS CAUDA
LIBRA
Path of the Sun (ecliptic)
Antares
M4
SCORPIUS
LUPUS
M83
NGC 5128
CENTAURUS

HOW TO USE THIS MAP

This map portrays the sky as seen near 35° north latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

midnight May 1
11 P.M. May 15
10 P.M. May 31

Planets are shown at midmonth

MAP SYMBOLS

◌ Open cluster
⊕ Globular cluster
□ Diffuse nebula
⌖ Planetary nebula
⬭ Galaxy

STAR MAGNITUDES

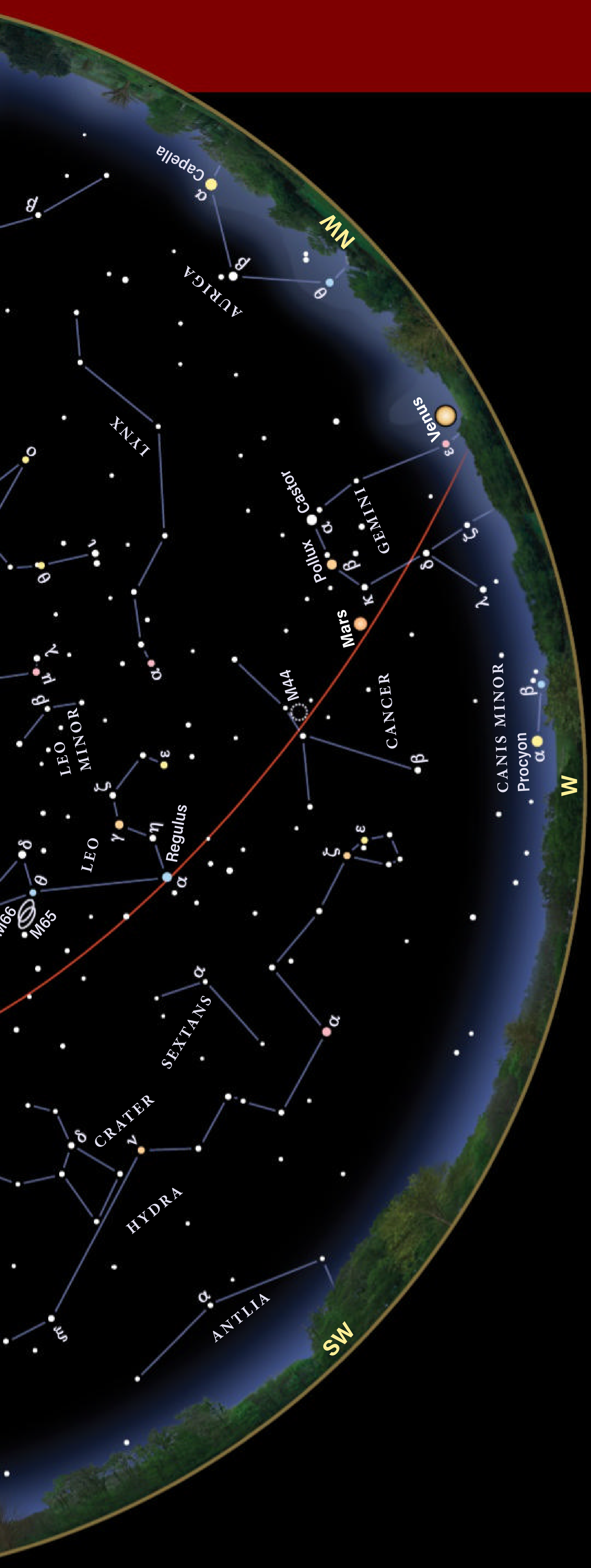
● Sirius
● 0.0
● 1.0
● 2.0
• 3.0
• 4.0
· 5.0

STAR COLORS

A star's color depends on its surface temperature.

- ■ The hottest stars shine blue
- ■ Slightly cooler stars appear white
- ■ Intermediate stars (like the Sun) glow yellow
- ■ Lower-temperature stars appear orange
- ■ The coolest stars glow red
- ■ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

BEGINNERS: WATCH A VIDEO ABOUT HOW TO READ A STAR CHART AT **www.Astronomy.com/starchart.**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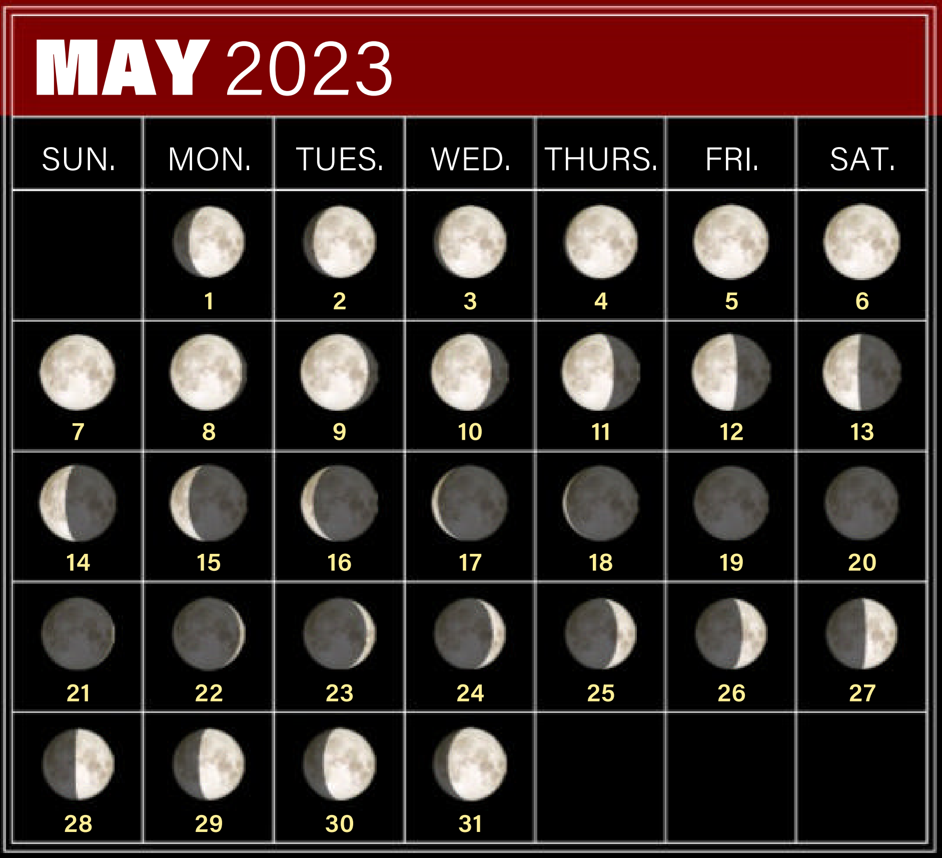
MAY 2023



SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
	1	2	3	4	5	6
7	8	9	10	11	12	13
14	15	16	17	18	19	20
21	22	23	24	25	26	27
28	29	30	31			

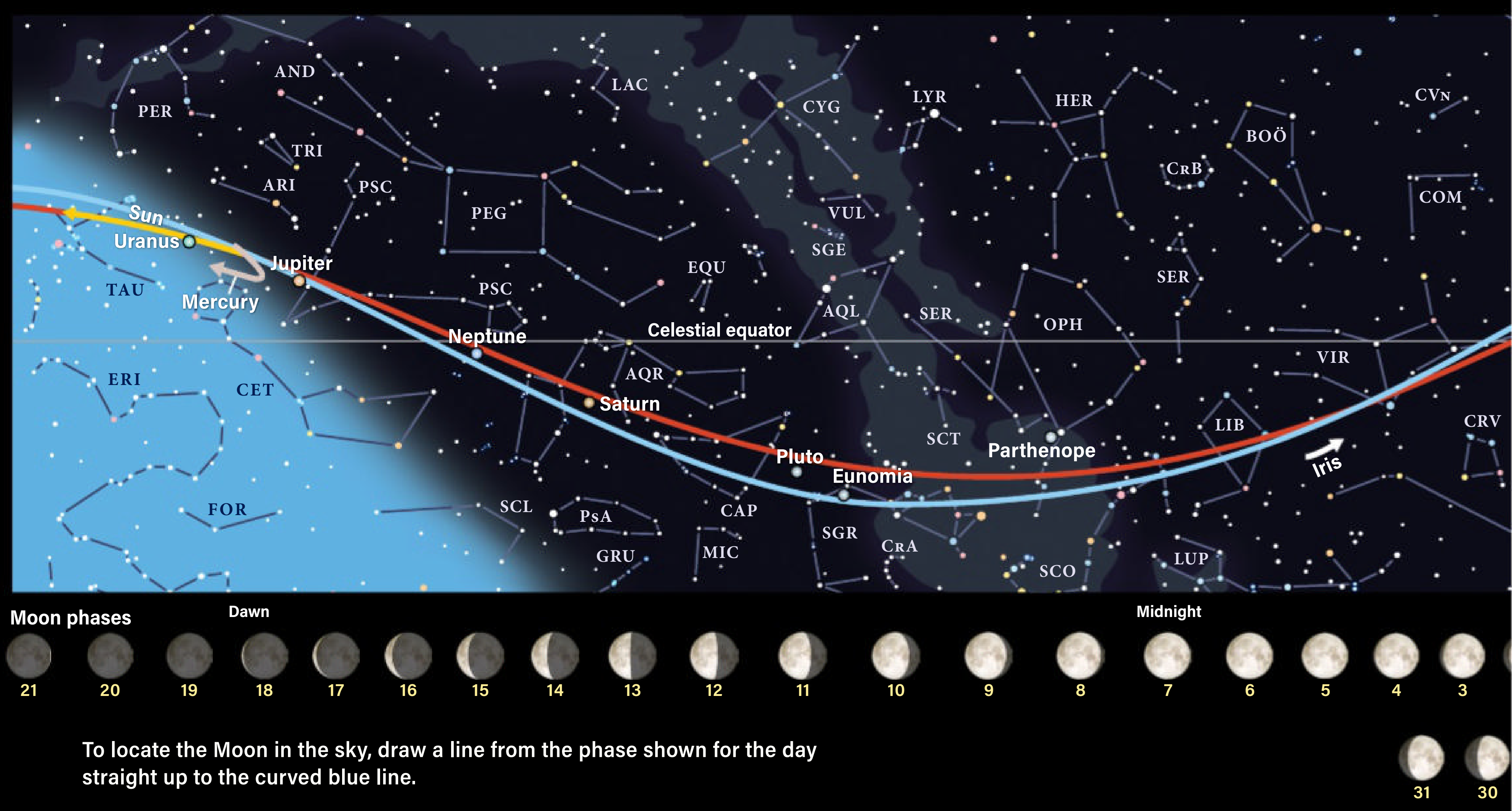
ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1	Mercury is in inferior conjunction, 7 P.M. EDT
2	Pluto is stationary, 7 P.M. EDT
5	Full Moon occurs at 1:34 P.M. EDT; penumbral lunar eclipse
6	Eta Aquariid meteor shower peaks
9	Uranus is in conjunction with the Sun, 4 P.M. EDT
10	Mars passes 5° south of Pollux, 4 P.M. EDT
11	The Moon is at perigee (229,449 miles from Earth), 1:05 A.M. EDT
12	Last Quarter Moon occurs at 10:28 A.M. EDT
13	Dwarf planet Ceres is stationary, 7 A.M. EDT
	The Moon passes 3° south of Saturn, 9 A.M. EDT
14	Mercury is stationary, 3 A.M. EDT
	The Moon passes 2° south of Neptune, 9 P.M. EDT
17	The Moon passes 0.8° north of Jupiter, 9 A.M. EDT
	The Moon passes 4° north of Mercury, 10 P.M. EDT
19	New Moon occurs at 11:53 A.M. EDT
23	The Moon passes 2° north of Venus, 8 A.M. EDT
24	The Moon passes 4° north of Mars, 2 P.M. EDT
25	The Moon is at apogee (251,350 miles from Earth), 9:39 P.M. EDT
27	First Quarter Moon occurs at 11:22 A.M. EDT
29	Mercury is at greatest western elongation (25°), 2 A.M. EDT
30	Venus passes 4° south of Pollux, noon EDT
	Mars is at aphelion (155 million miles from the Sun), 5 P.M. EDT

PATHS OF THE PLANETS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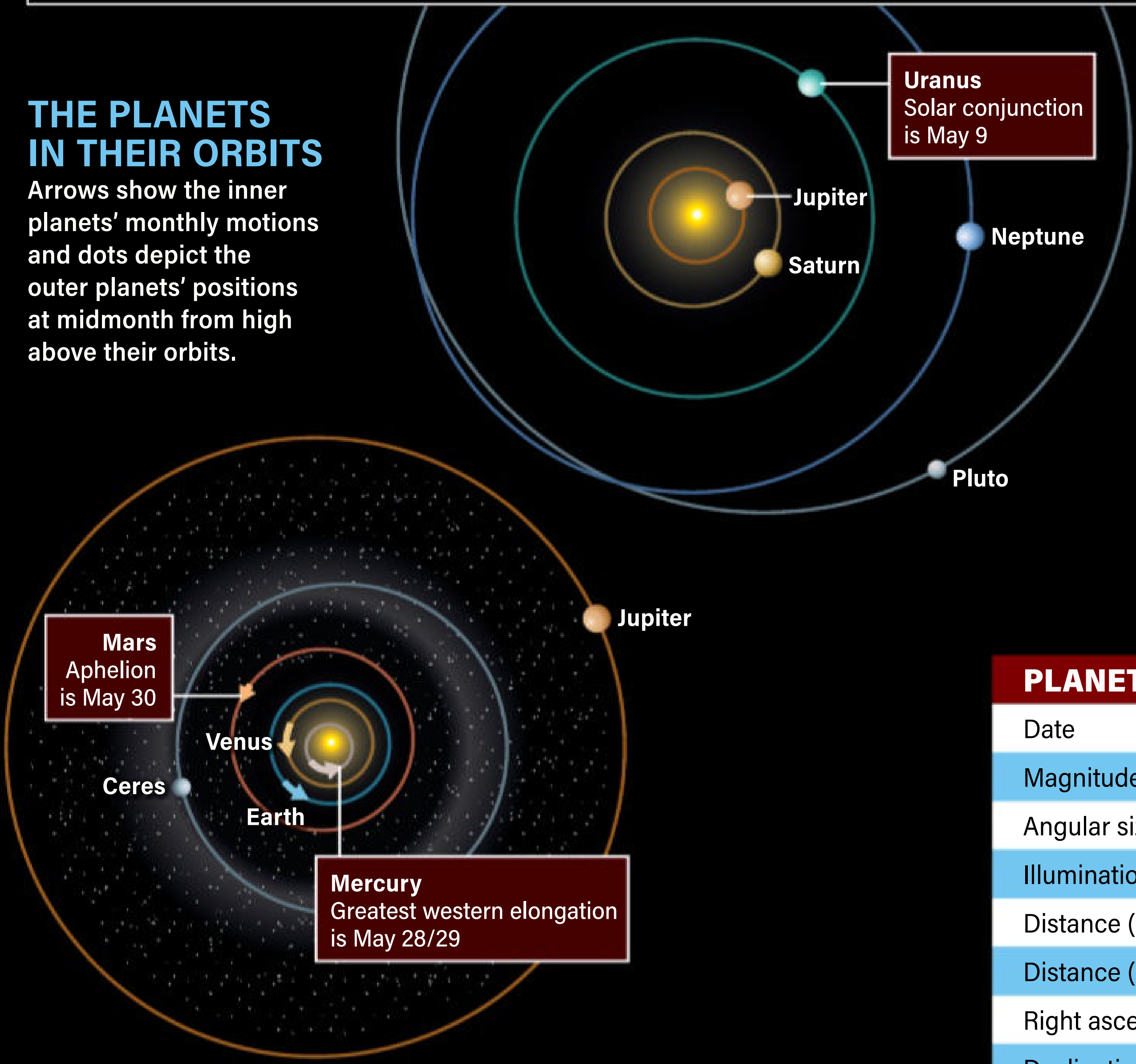
30

To locate the Moon in the sky, draw a line from the phase shown for the day straight up to the curved blue line.

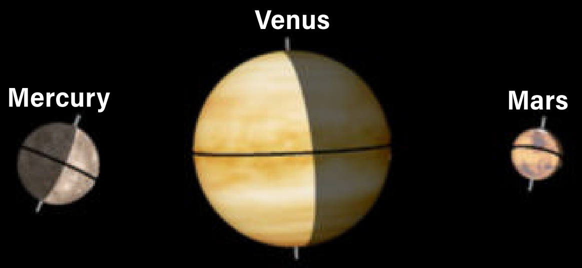
THE PLANETS IN THEIR ORBITS

Arrows show the inner planets' monthly motions and dots depict the outer planets' positions at midmonth from high above their orbits.


Uranus
Solar conjunction is May 9
Jupiter
Saturn
Neptune
Pluto
Jupiter
Mars
Aphelion is May 30
Venus
Ceres
Earth
Mercury
Greatest western elongation is May 28/29

THE PLANETS IN THE SKY

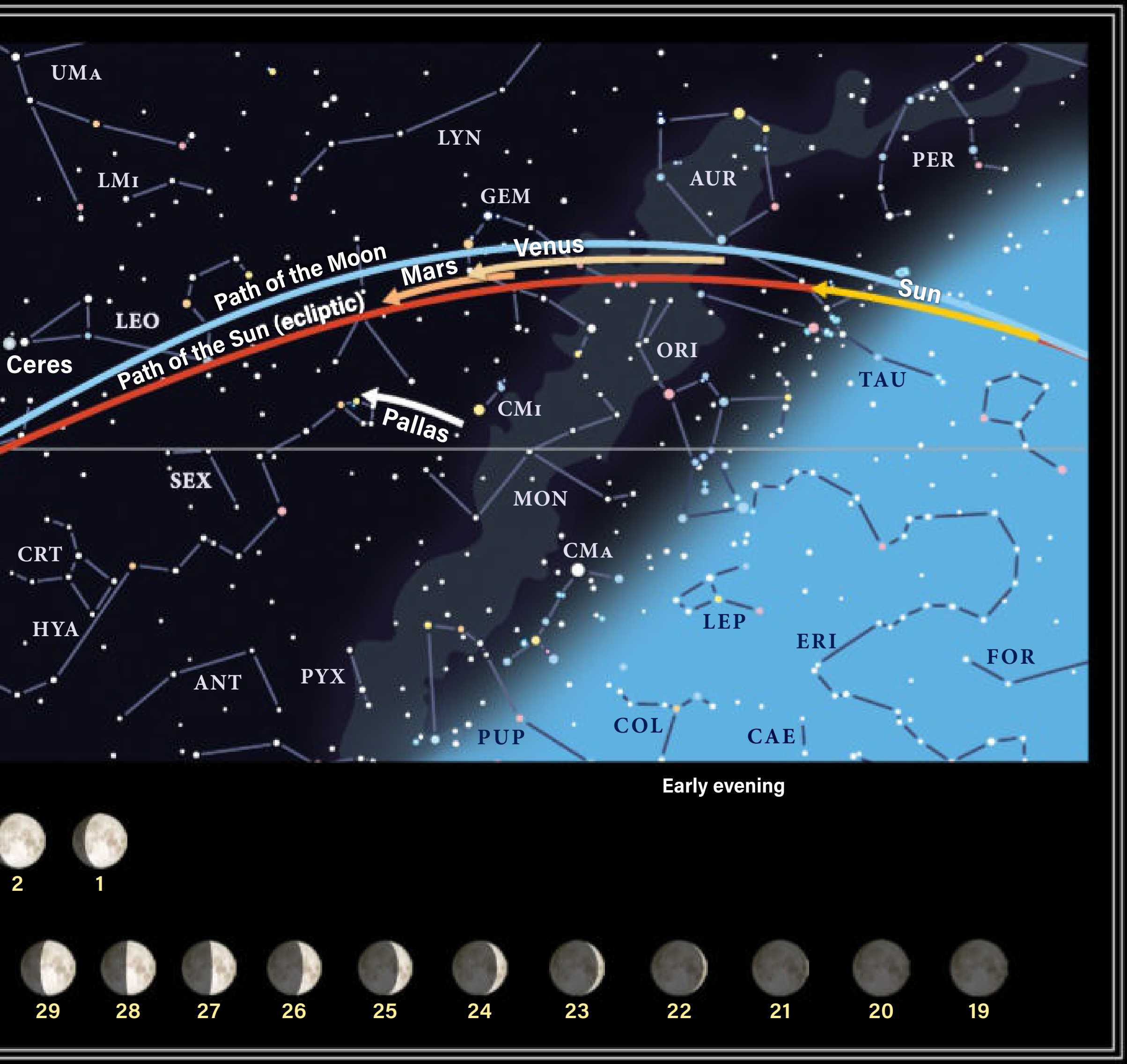
These illustrations show the size, phase, and orientation of each planet and the two brightest dwarf planets at 0h UT for the dates in the data table at bottom. South is at the top to match the view through a telescope.


Venus
Mercury
Mars

PLANETS	MERCURY	VENUS
Date	May 31	May 15
Magnitude	0.4	–4.2
Angular size	7.9"	19.1"
Illumination	42%	60%
Distance (AU) from Earth	0.850	0.874
Distance (AU) from Sun	0.431	0.720
Right ascension (2000.0)	2h52.0m	6h34.3m
Declination (2000.0)	12°52'	25°58'

This map unfolds the entire night sky from sunset (at right) until sunrise (at left). Arrows and colored dots show motions and locations of solar system objects during the month.

MAY 2023

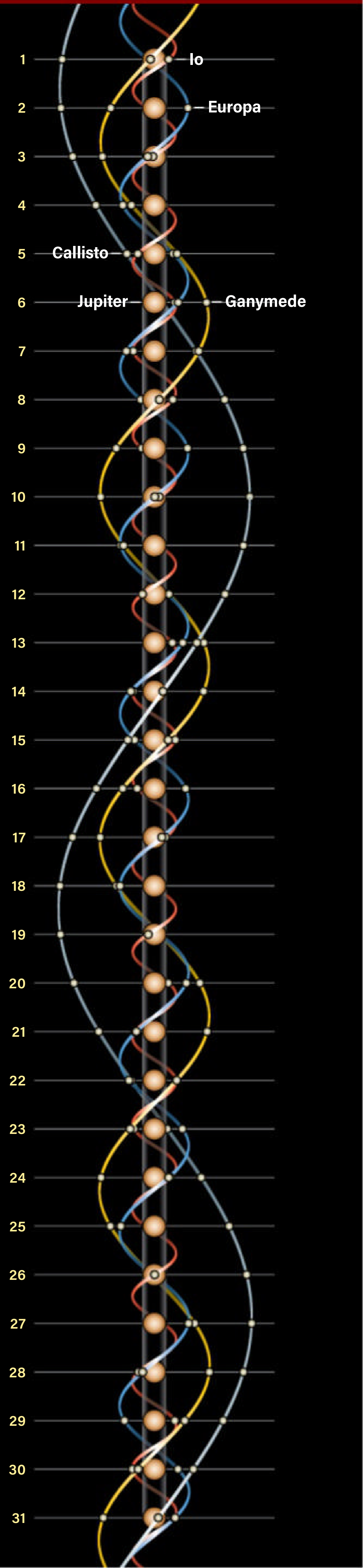


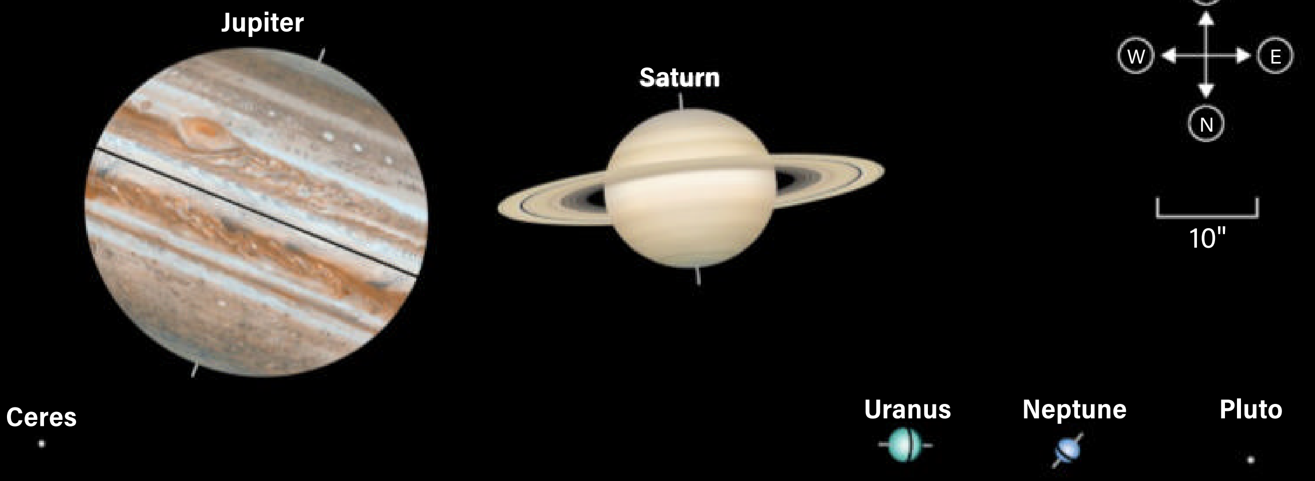
UMA
LMI
LYN
GEM
AUR
PER
LEO
Ceres
Path of the Moon
Path of the Sun (ecliptic)
Mars
Venus
Sun
ORI
TAU
CMI
Pallas
SEX
MON
CRT
CMA
HYA
LEP
ERI
FOR
ANT
PYX
PUP
COL
CAE
Early evening
2
1
29
28
27
26
25
24
23
22
21
20
19

Callisto
Europa
Io
Ganymede

JUPITER'S MOONS

Dots display positions of Galilean satellites at 6 A.M. EDT on the date shown. South is at the top to match the view through a telescope.





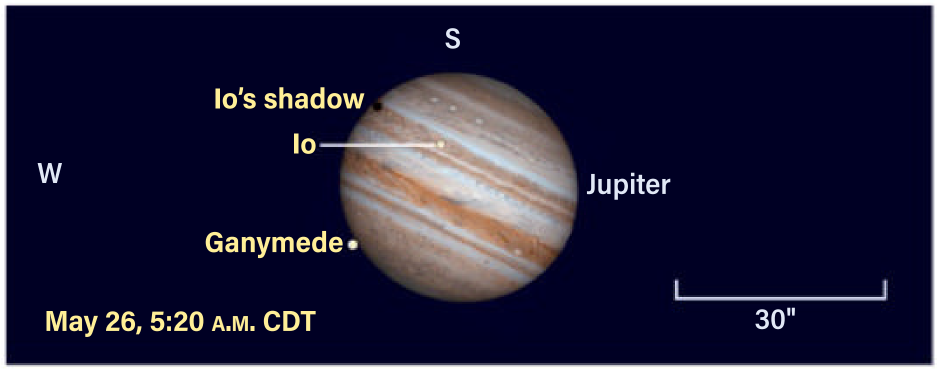
Jupiter
Saturn
S
W
E
N
10"
Ceres
Uranus
Neptune
Pluto

MARS	CERES	JUPITER	SATURN	URANUS	NEPTUNE	PLUTO
May 15	May 15	May 15	May 15	May 15	May 15	May 15
1.5	7.9	–2.1	0.8	5.9	7.8	15.2
5.0″	0.7″	33.7″	16.7″	3.4″	2.2″	0.1″
92%	97%	100%	100%	100%	100%	100%
1.861	1.944	5.858	9.967	20.657	30.450	34.350
1.665	2.593	4.955	9.801	19.650	29.909	34.767
7h55.3m	11h58.0m	1h50.5m	22h33.2m	3h06.2m	23h50.1m	20h11.0m
22°27′	14°26′	10°13′	–10°41′	17°09′	–2°22′	–22°38′

SKY THIS MONTH

— *Continued from page 29*

In short order



Shortly before sunrise in the Midwest on May 26, Io and its shadow are crossing the face of Jupiter. Io's shadow will slip off the disk moments before Ganymede disappears in an occultation. Europa is behind Jupiter and not visible at this time; Callisto lies far east of the planet.

Mars ends the month only 1° shy of M44: a beautiful pairing setting up the first couple of days of June, when Mars crosses the cluster. Note that Venus stands only 11° away, a few degrees south of Pollux. Through a telescope, Mars presents a tiny disk spanning 5", making it a challenge to see any surface detail except under perfect conditions. The Red Planet, now passing 2 astronomical units from Earth, sets soon after midnight. (One astronomical unit, or AU, is the average Earth-Sun distance.)

Saturn rises about 3:30 A.M. local time on May 1 and is up by 1:30 A.M. on May 31. Its altitude improves greatly in the hour before dawn throughout the month. It lies in mid-Aquarius and is by far the brightest object (magnitude 0.8 most of the month) in the vicinity. Fomalhaut in Piscis Austrinus is the closest 1st-magnitude star. It lies about 20° to Saturn's south and rises about 90 minutes later.

The hour before dawn is a fine time to view the ringed planet, when Saturn stands at more than 20° elevation in the southeastern sky. The rings are tilted by 8° to our line of sight, presenting a beautiful view. Both northern and southern hemispheres of the disk are on show, spanning 17". It's a good time to look out for any storms brewing in the normally quiescent saturnian atmosphere.

Saturn's brightest moon, Titan, shines at magnitude 8.7. It stands due north of the planet on May 4 and 20, and due south on May 12 and 28. Other moons are fainter and closer in, while Iapetus, farther out, reaches its faint eastern elongation on May 14. We will revisit these moons in the coming months as Saturn's visibility improves.

Lying at the remote edge of our solar system, the distant planet **Neptune** can be spotted with binoculars. It shines at magnitude 7.8. The ice giant rises nearly an hour after Saturn and remains low in the east an hour before dawn on May 1, a difficult object to spot.

Neptune's visibility improves by May 31, when it stands about 20° high in the eastern sky at the onset of twilight. The dim

WHEN TO VIEW THE PLANETS

EVENING SKY
Venus (west)
Mars (west)

MIDNIGHT
Mars (west)

MORNING SKY
Mercury (east)
Jupiter (east)
Saturn (southeast)
Uranus (east)
Neptune (east)

26° Venus reaches its maximum declination north (26°) and its highest point above the ecliptic this month.

COMET SEARCH | Practice, patience, and power

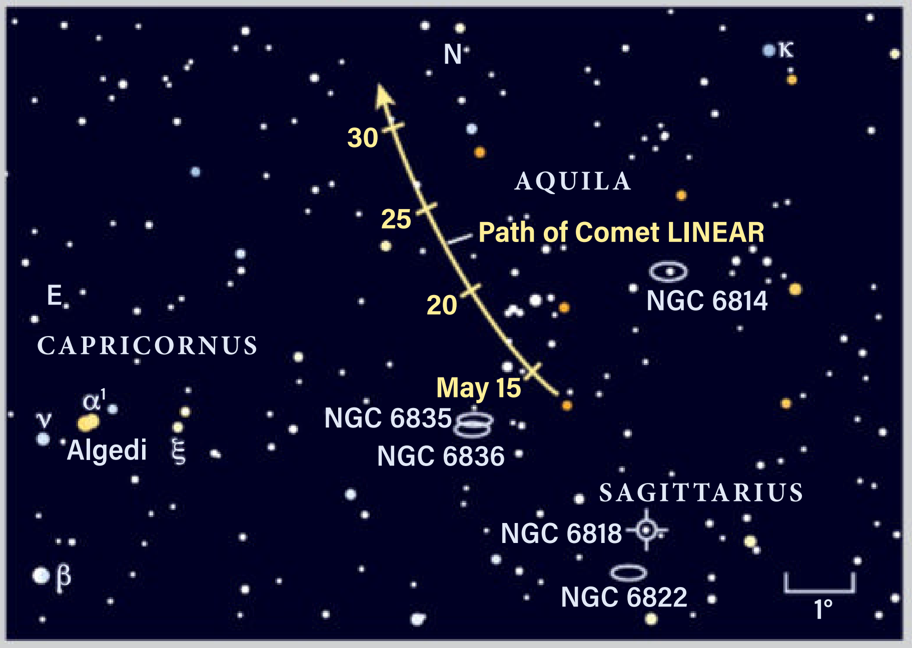
WITH A PAUSE in bright comets, take advantage of milder spring nights to leave the rush behind and push your skills in detecting faint structure over a range of magnifications.

Under a dark sky in the second half of the month, begin at low power on the Lagoon Nebula (NGC 6523) after midnight. Shift 1.5° east-northeast to NGC 6559. Imagine the 10th-magnitude star at its center is the core of a comet, then push it to the side. Slowly swoop the scope around, keeping the star just outside the edge of the field. The uneven nebula should be rewarding because one side is long and narrow like a comet tail.

Next, jump to northeastern Sagittarius and NGC 6822. Half the apparent diameter of the Moon, the dwarf elliptical galaxy can be seen in a 4-inch scope. Not even a degree north lies a magnitude 9.4 version of Uranus: planetary nebula NGC 6818, also called the Little Gem. Crank up the power to extract shape and brightness differences from a starting estimate of round.

From there, some 5° north-northeast lands us at Comet 237P/LINEAR. If it is in outburst, an 8-inch scope will do it, but more likely you'll need a 12-inch mirror to see the 13th-magnitude fuzz. Use 150x or more to darken the sky background and make the small cloud of dust appear big enough for your brain to recognize it. To the south, the pair of magnitude 12.5 and 12.9 galaxies serve as a comparison. LINEAR never crosses Mars' orbit, but every 6.6 years loops out to Jupiter's domain.

Comet 237P/LINEAR



Try to spot Comet 237P/LINEAR in the second half of the month — though note that unless it experiences an outburst, you'll need a large scope to do the job. Fortunately, there are plenty of other targets nearby.

bluish object lies within 1° of 20 Piscium, a 5th-magnitude field star, forming a triangle together with 24 Piscium. The three lie some 5° southeast of 4th-magnitude Lambda (λ) Piscium. From night to night, Neptune wanders east, farther from 20 Piscium.

Jupiter sits about 10° above the eastern horizon one hour before sunrise at the end of May. The giant planet reappears in the morning sky among the stars of Aries the Ram, shining at an easy-to-spot magnitude of –2.1. May is a good time to get acquainted with Jupiter again after a couple of months of limited viewing. Check on its atmospheric activity to see if any new features have arisen after solar conjunction.

Don't miss the lunar occultation of Jupiter the morning of May 17. The exact timing of the event varies based on your location. Watch the pair rise around 4:30 A.M. local time and, as twilight brightens in the Midwest (it's already daylight on the East Coast), the limb of the Moon approaches Jupiter, hiding the giant planet around 7:11 A.M. EDT in Miami, 7:21 A.M. EDT in Atlanta, 7:45 A.M. EDT in Boston, 6:29 A.M. CDT in Kansas City, 6:36 A.M. CDT in Chicago, and 6:32 A.M. CDT in Denver. It takes almost a minute for the Moon to completely cover the planet.

The first mutual Galilean satellite event that you can easily observe occurs May 26, when Io and its shadow are crossing Jupiter's disk as the planet rises. As twilight grows across the Midwest, Io's shadow leaves the disk at 5:24 A.M. CDT. Ganymede soon disappears behind the same limb of Jupiter at 5:27 A.M. CDT.

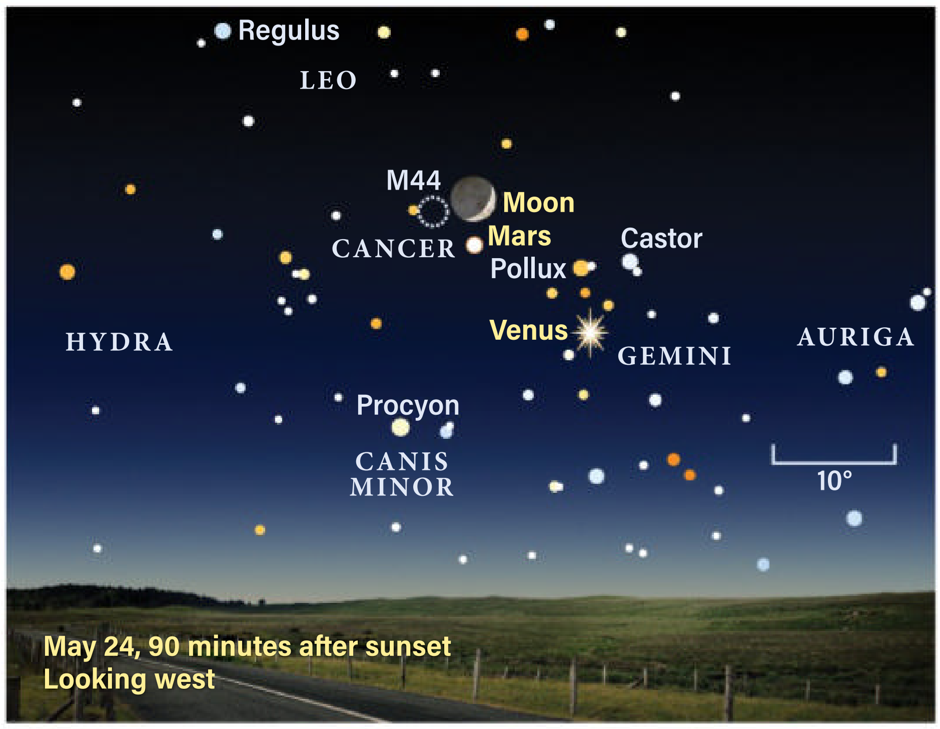
Uranus is too close to the Sun for observation during much of the month. Catch it in the half hour before sunrise in late May.

Mercury reaches inferior conjunction May 1 and moves into the morning sky shortly after, but remains faint and beyond reach for the first three weeks of the month. On May 23, it reaches magnitude 1 and is located 7° due east of brighter Jupiter, which acts as a nice guide to finding the innermost planet. Mercury is 4° high 30 minutes before sunrise. Six days later, it reaches its greatest elongation west of the Sun (25°) at magnitude 0.5. Its location south of the ecliptic keeps Mercury hugging the eastern horizon while Jupiter pulls away, higher in the sky. At the end of May, the two planets are separated by a dozen degrees.

A deep penumbral eclipse of the Moon occurs on the evening of May 5 for observers in Africa, Asia, Australia, and New Zealand. For most of the eclipse not much is evident, but during greatest eclipse (17:24 UTC), when more than 90 percent of the Moon is inside the penumbra, the northern limb will appear noticeable dusky. The eclipse is not visible from the U.S.

Martin Ratcliffe *is a planetarium professional with Evans & Sutherland and enjoys observing from Salt Lake City.* **Alister Ling**, *who lives in Edmonton, Alberta, is a longtime watcher of the skies.*

Meet me at the Beehive



The Moon and Mars congregate near the Beehive Cluster (M44) in late May. As our satellite moves away, Mars inches closer to the young group of stars.

GET DAILY UPDATES ON YOUR NIGHT SKY AT **www.Astronomy.com/skythisweek.**

LOCATING ASTEROIDS

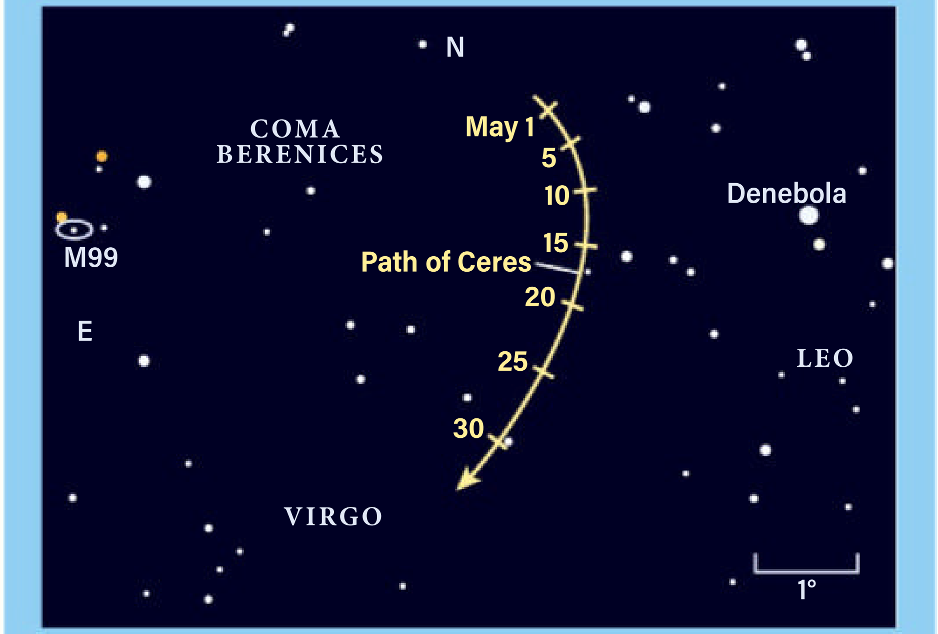
Easy pickings

PERFECT FOR A SMALL SCOPE in the suburbs, magnitude 7.7 1 Ceres rides with Leo high in the south as darkness sets in. It's only half a binocular field east (left) of the bright star Denebola. (That name's Arabic roots mean "tail of the lion." Deneb of the Summer Triangle is the tail of Cygnus the Swan, but over time its full name was shortened to its current moniker.)

There are so few background stars here that our target will often be the brightest dot in the field of view. However, you won't see it shift during an observing session. The main-belt asteroid is just coming out of the western end of its retrograde loop as Earth runs ahead on our inner orbit, making Ceres appear to move slowly. But plotting it against four other stars in a logbook every third night will show the shift.

Don't bother when Moon is nearby — May 1 and the 27th onward — because the scattered light will make a sighting difficult. A spherical 600 miles across, Ceres was the first asteroid discovered and was later offered a spot in the dwarf planet club.

Turning tail



Ceres skims just east of Denebola this month, moving through a region relatively devoid of background stars.

Minor gems of the SPRING SKY

Faint but not forgotten: See 20 lesser-known deep-sky objects this month.

BY MICHAEL E. BAKICH

Draco Trio
This stunning collection of faint galaxies lies in the constellation Draco the Dragon.
DAN CROWSON

MANY AMATEUR ASTRONOMERS start observing with the Messier catalog, a list of "fuzzy" deep-sky targets that present wonderful sights through a telescope. Although Messier objects may be bright and well known, there's so much more in the sky to enjoy. The following list of beautiful globular clusters, galaxies, and other celestial entities of the spring sky is for the dedicated amateur astronomer who's ready to take the next step in deep-sky observing.

These targets aren't too faint, but they are certainly not standouts like M13 or M8, and may not rise very high or at all in northern latitudes. So, move away from the crowd and treat yourself to some lesser-seen wonders. If you observe each one in the order listed below, the latter items lie farther east (and rise later), so you'll have more time to enjoy them.

Peer into space

Once your telescope reaches ambient temperature, point it at globular cluster **NGC 5634** in Virgo. Of the 200 deep-sky objects in this constellation that are brighter than 13th magnitude, this is the only one that's not a galaxy. It glows at magnitude 9.5 and spans 5.5'. To find it, look midway between Syrma (Iota [ι]

NGC 5907

NGC 5907, also known as the Splinter Galaxy, tilts 3.5° from our line of sight and has a long, narrow center.

ADAM BLOCK

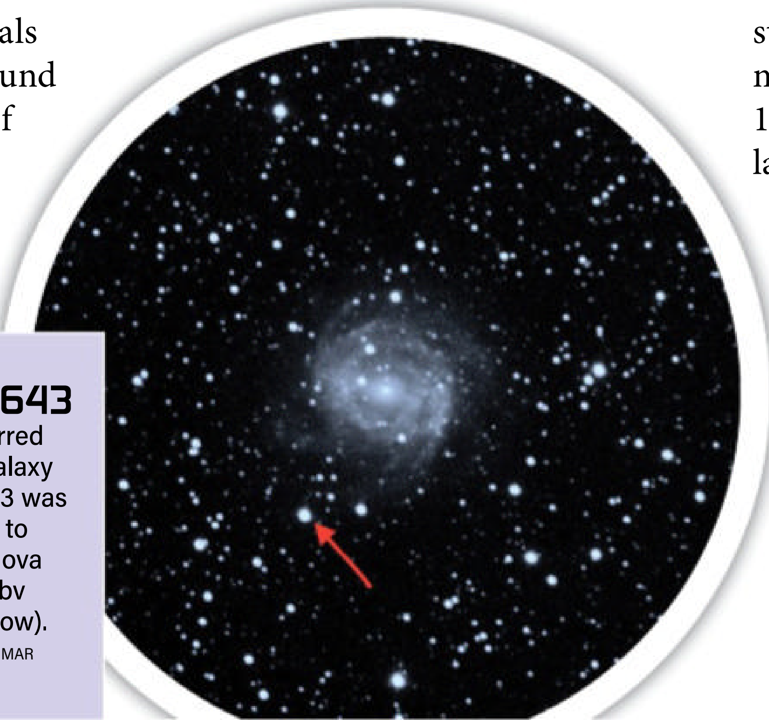
Virginis) and Mu (μ) Virginis. Through a 4-inch scope, you'll spot a relatively bright (8th magnitude) orange star that is not part of the cluster, and a hazy circle of stars that require a larger scope to resolve them into individual points.

The second stop on our list lies in Lupus the Wolf. Barred spiral galaxy **NGC 5643** is 2.1° south-southwest of Eta (η) Centauri. A 6-inch scope reveals a magnitude 10.4 disk that is fairly round (5.1' by 4.3') and evenly illuminated. If you have access to a larger (say, an 11-inch) scope, crank the power to 300x and see if the northern half of the galaxy looks brighter than the southern half. Then look for the bar, which runs east-west. It's not easy to see because the spiral arms are just as bright.

Our third target is globular cluster **NGC 5694** in Hydra. At magnitude 9.2, this is a bright globular. It lies nearly 2° west-southwest of the 5th-magnitude star 56 Hydrae at the far eastern end of that constellation. The cluster spans only 3.6' and it contains faint stars that don't resolve well. If you crank up the power, several superimposed foreground stars will appear.

Slide back into Lupus for open cluster **NGC 5749**. It glows at magnitude 8.8 and spans 7'. Center on Zeta (ζ) Lupi and then move your scope 4.2° southwest. A small telescope will reveal about a dozen stars, the brightest of which shines at magnitude 9.6. If you move up to an 11-inch scope, you'll just perceive a new layer of indistinct background stars.

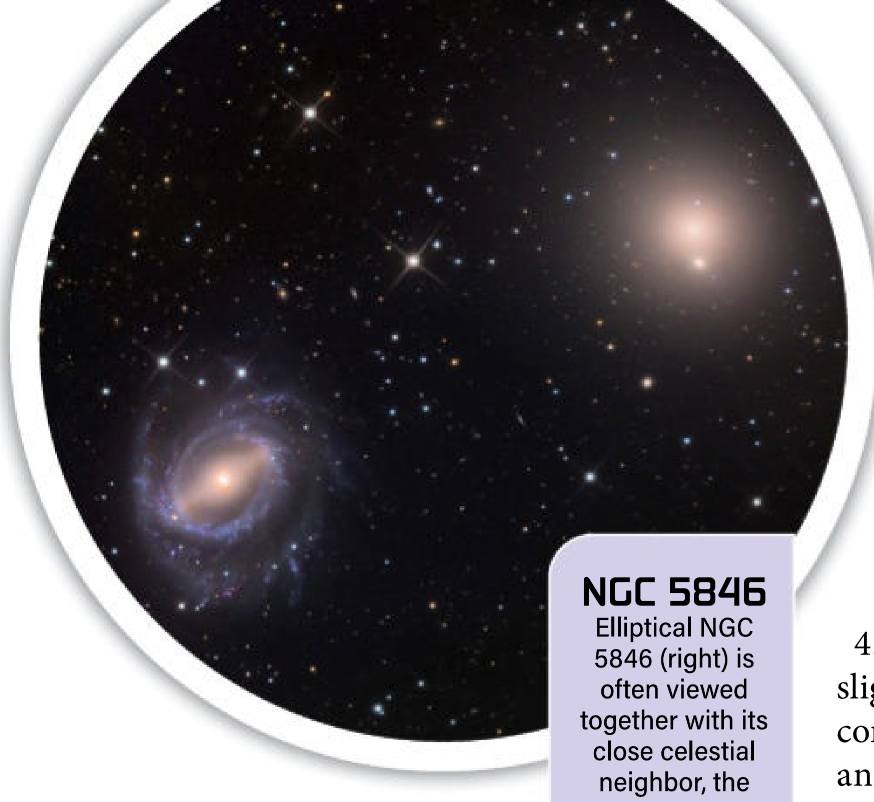
Our next target, also in Lupus, rivals Messier objects in brightness. Open cluster **NGC 5822** glows at magnitude 6.5, which puts it in the range of naked-eye sightings by sharp-eyed observers from a dark site. It also sports a diameter of 35', slightly larger than the Full Moon. To locate it, point binoculars or a



NGC 5643

The barred spiral galaxy NGC 5643 was home to Supernova 2017cbv (red arrow).

RICH HAMMAR



NGC 5846
Elliptical NGC 5846 (right) is often viewed together with its close celestial neighbor, the fainter spiral galaxy NGC 5850. ADAM BLOCK/MOUNT LEMMON SKYCENTER/UNIVERSITY OF ARIZONA/WIKIMEDIA COMMONS

telescope 2.6° south-southwest of Zeta Lupi. Use a 4-inch scope and an eyepiece that gives medium power, and you'll see roughly 50 stars.

Another nice object in Lupus is globular cluster **NGC 5824**. It glows at magnitude 9.1 and measures 7.4' across. You'll find it 5° northwest of Phi^1 (ϕ^1) Lupi. Insert an eyepiece that gives a magnification around 150x into an 8-inch scope. Look for a packed central region, an irregular edge, and a couple of faint stars in the dim halo.

For our next target, the **Ursa Minor Dwarf Galaxy** (UGC 9749), head to the far north. This dwarf elliptical galaxy lies 4.7° south-southwest of magnitude 3.0 Pherkad (Gamma [γ] Ursae Minoris). It glows at magnitude 10.9 but measures a staggering 41' by 26', which means it covers an area 40 percent larger than the Full Moon. Because the UMi Dwarf has a low surface brightness, the bigger the telescope you point at it, the better. Start at a dark site on a moonless night. Use your lowest-power eyepiece and sweep back and forth, searching for a Moon-sized glow that's ever-so-slightly brighter than the background sky.

NGC 6124
The open cluster NGC 6124 is in the constellation Scorpius the Scorpion. It contains some 125 visible stars. ROBERTO MURA/WIKIMEDIA COMMONS

As you leave the dwarf elliptical, head south for the true elliptical galaxy: **NGC 5846** in Virgo. You'll find it 1° east-southeast of the magnitude 4.4 star 110 Virginis. It has a slight oval shape, a small bright core, and a wide halo. Through an 8-inch or larger scope at a dark site, this becomes a 2-for-1 treat. NGC 5846 glows at magnitude 10.1 and measures 4' by 3.7'. But glance just 10' to the east-southeast and you'll see spiral galaxy **NGC 5850**, glowing a bit fainter at magnitude 10.8.

Next up is a personal favorite of mine, spiral galaxy **NGC 5907** in Draco. It lies 3° south-southwest of Iota Draconis and glows at magnitude 10.3. But it's not its brightness that makes NGC 5907 cool. Rather, it's because this is a true edge-on spiral whose plane tilts a scant 3.5° from our line of sight. It measures 11.5' by 1.7', but through a 4-inch scope you'll only detect half that length. Bigger apertures won't show more detail, but they will allow you to see more of the galaxy's length.

As you move through this list, you'll undoubtedly run across a few objects that will be moderately hard to see. I rank globular cluster **Palomar 5** as the most difficult. It lies in Serpens some 9° west-northwest of Mu Serpentis.

Pal 5's magnitude, 11.8, is only part of what makes it a tough catch. With a diameter of 7', it's large enough that its surface brightness is quite low. The best strategy for finding it is to point an 11-inch scope toward the area and move back and forth. Use a medium-power eyepiece to see the gradual lightening of the backdrop of space.

Our next object is planetary nebula **NGC 5882** in Lupus; at magnitude 9.4, it's bright enough to appear blue-green to most observers. The most visible section is only 7" across, but an 11-inch scope at high power (250x and above) will reveal its circular shell. To locate it, look 1.4° southwest of Epsilon (ε) Lupi.

When you're done with NGC 5882, head north to neighboring Libra for that constellation's standout deep-sky object, globular cluster **NGC 5897**, often referred to as the Ghost Globular because it resembles a ghostly image of the much brighter globular M5. That may be true, but with a diameter of 12.6' and a magnitude of 8.6, this object is big (40 percent the diameter of the Full Moon) and relatively bright all on its own. You'll find it 8° southeast of Zubenelgenubi (Alpha^2 [α^2] Librae). The first thing most observers notice is that the stars at the cluster's core are loosely concentrated. An 8-inch scope at a dark site reveals only a dozen or so suns superimposed on a faint glow.

Next, head to Serpens for barred spiral **NGC 5921**. It lies 5.7° west-southwest of Unukalhai (Alpha Serpentis). The galaxy glows at magnitude 10.8 and measures 4.9' by 4.2'. If you can view it through an 11-inch scope at a dark site, keep cranking up the power until the bar appears. At first, you might think the magnitude 11.6 star at NGC 5921's southwestern edge is a supernova. Sorry — it's just a foreground star.

If your observing site is far enough south, move east of Lupus to the faint constellation Norma and take a look at open cluster **NGC 5925**. It lies 3.3°

NGC 5634
NGC 5634 is a bright globular cluster with a magnitude 8 orange star, SAO 139967, to the east-southeast. YU-HANG KUO/FLICKR

NGC 5921
A large target in the constellation Serpens, NGC 5921 is some 75 million light-years from Earth.
ADAM BLOCK

southeast of Zeta Lupi, glows at magnitude 8.4, and measures 14' across. A 6-inch scope reveals about three dozen 10th- to 12th-magnitude stars. Step up to an 11-inch scope, and you'll see 50 more.

Good old Zeta Lupi also can lead us to our next target, globular cluster **NGC 5927**. For this one, move 2.9° northeast of the star. This nice object glows at magnitude 8.0 and sports a diameter of 12'. An 8-inch or larger scope will reveal a dense core with a ragged outer edge. Larger instruments will resolve more stars, but the core will look just as dense.

NGC 5907 IS A TRUE EDGE-ON SPIRAL WHOSE PLANE TILTS A SCANT 3.5°.

Our next target is actually a threesome of galaxies, sometimes called the **Draco Trio**. To locate it, aim your telescope 1.8° east-northeast of Iota Draconis. The galaxies lie in an east-west line only 14' long. None of the objects are bright, so head to a dark site and be patient. Spiral NGC 5985 registers at a magnitude of 14.2, while the elliptical NGC 5982 is magnitude 12.4, and finally, spiral NGC 5981 comes in at a magnitude of 13.6. Through an 11-inch scope, the only one to show detail will be NGC 5982, which measures 5.3' by 2.9'. Crank up the power and try to detect its smooth, disklike shape.

Next, head south one final time to Zeta Lupi, then move 2.8° west to find globular cluster **NGC 5986**. It glows at magnitude 7.5 and has a diameter of 9.8'. Through a medium-size scope, this cluster looks irregular and mottled. Move up to an 11-inch scope, and you'll resolve several dozen stars.

Travel across the border from Lupus to Scorpius to find the nice open cluster **NGC 6124**, also known as Caldwell 75. It lies not quite 6° southwest of Mu Scorpii. Sharp-eyed observers can pick out this magnitude 5.8 object with their naked eyes. It's big, too. With a diameter of 29', it's nearly the size of the Full Moon. A 4-inch scope at medium power will let you count 50 stars. Insert a low-power eyepiece, however, and you'll see that the cluster has a wedge shape that points roughly to the southeast.

Another factor making the view interesting is that NGC 6124 sits in front of a region of dark nebulae. This position makes it stand out well.

Although our next target, globular cluster **NGC 6144** in Scorpius, glows somewhat softly at magnitude 9.0, it's still pretty easy to find. Just center Antares (Alpha Scorpii) and move your scope 0.6° to the northwest. The cluster has a fair diameter — 9.3' — but it's a distant object, so stars near its core are not easy to resolve. Use at least an 8-inch scope at 200x, and the outer members should start to pop into view.

The final object on our list is an asterism: the **Mini Coathanger** in Ursa Minor. *Astronomy* magazine Contributing Editor Phil Harrington named this asterism because he thought it looked like the Coathanger (Collinder 399), which is in Vulpecula. The Mini Coathanger lies 1.9° south-southwest of Epsilon Ursae Minoris. It's formed by 10 stars ranging in brightness from magnitude 9.2 to 10.8. This isn't a tiny object. The Mini Coathanger measures 9' from the top of its hook to its base, which itself spans 17', more than half the diameter of the Full Moon.

I hope these 20 under-observed celestial wonders give you as much pleasure at the telescope as they have for me.

Michael E. Bakich *is a contributing editor of* Astronomy *who often observes faint objects from his home in Tucson.*

Ursa Minor Dwarf
The Ursa Minor Dwarf lies in the southernmost part of the northernmost constellation.
URSA MINOR DWARF COMPOSITE PUBLIC DATA/ GIUSEPPE DONATIELLO/ WIKIMEDIA COMMONS

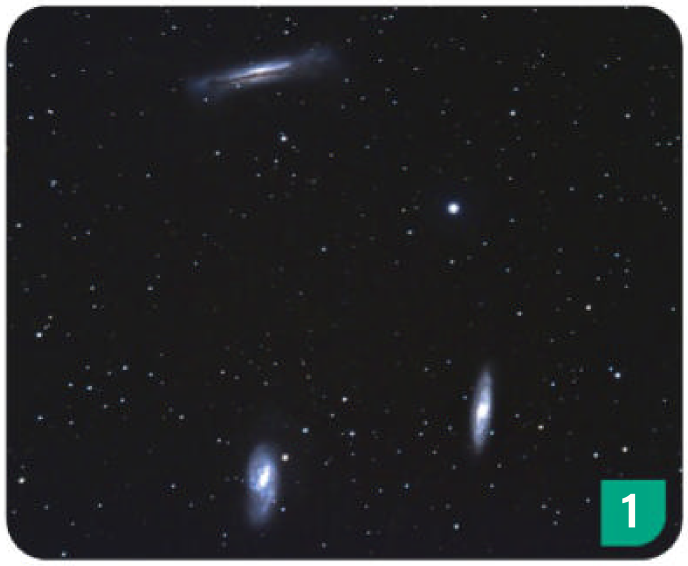
Target 10 galaxy groups

Although your backyard telescope can never reveal a view of Stephan's Quintet quite like this mid-infrared shot taken by the James Webb Space Telescope, the interacting set of galaxies is well worth tracking down. NASA, ESA, CSA, STSCI

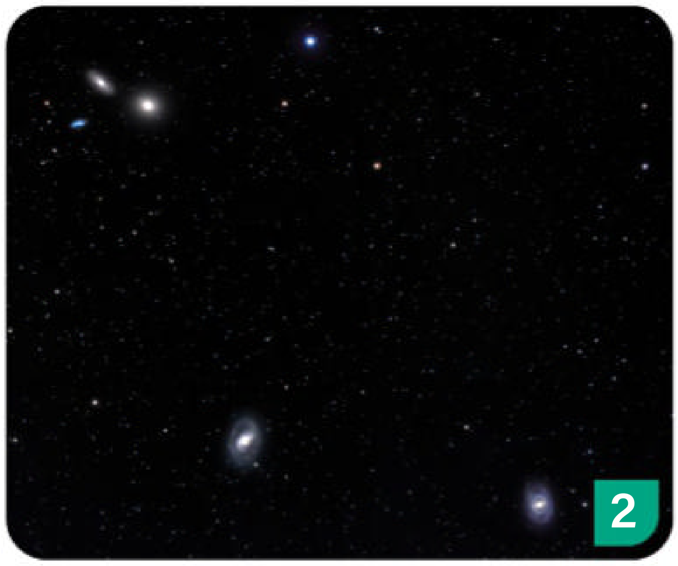
Take in a menagerie of galactic sights in a single view.

BY ALAN GOLDSTEIN

AS A LONG-TIME OBSERVER OF GALAXIES, I have a saying: "Why look at just one galaxy when you can look at multiple galaxies at the same time?" By observing groups and clusters, you not only get treated to the glow of potentially many trillions of stars all at once, but you can also survey the stunning diversity of galaxies without bouncing your scope around the entire sky.



1 LEO TRIPLET The Leo Triplet bursts into focus in this shot taken through a 5-inch Astro-Physics refractor at f/6 (no flattener) using a Canon 7D camera. NGC 3628 is at top, M66 is at bottom, and M65 is at bottom right. ALAN DYER



2 M95, M96, AND M105 This image, taken April 15, 2021, shows M95 (bottom right) and M96 (bottom center), both barred spirals. Of the three galaxies at top left, elliptical M105 sits farthest right. Moving counterclockwise from M105, also visible are NGC 3384 and NGC 3389. ALAN DYER

There is a hierarchy for galaxies and their groupings, and it starts with singles. But true isolated galaxies are surprisingly rare. Many galaxies — like our Milky Way — have a few neighbors. Collectively, these are called groups, and they are the smallest associations of gravitationally bound galaxies. Groups of galaxies may be part of larger clusters, and aggregates of those are called superclusters.

How do we distinguish a group from a cluster? A typical group consists of three to five larger galaxies with a smattering of dwarf galaxies in tow. Our Local Group, for instance, consists of three major galaxies (the Andromeda Galaxy [M31], the Milky Way, and the Triangulum Galaxy [M33]) along with a relatively large dwarf (the Large Magellanic Cloud) and several dozen small to tiny galaxies. Each large member of the Local Group contains significantly more mass and stars than are found in all the dwarf systems combined. A cluster, meanwhile, contains a larger number, typically hundreds, of "regular" galaxies, each with roughly between 100 billion and a trillion stars. Superclusters, in turn, are gravitationally bound collections of up to hundreds of thousands of individual galaxies.

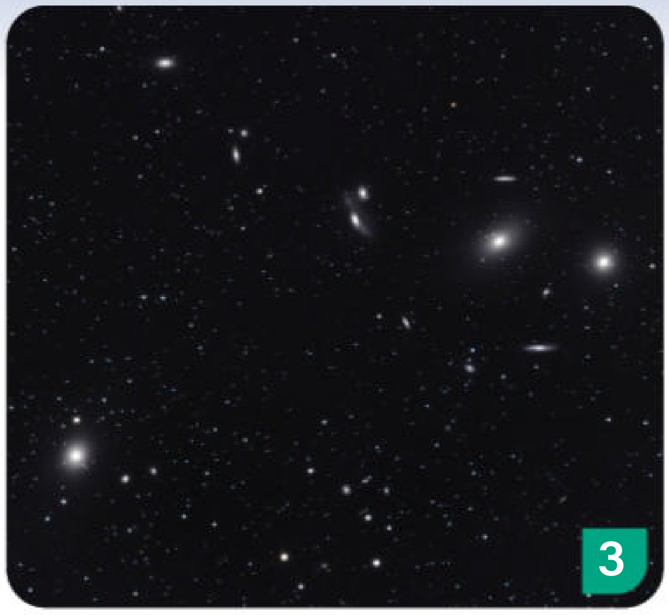
The closer a galaxy group is to us, the more widely its members appear scattered in the sky. For instance, at 13 million light-years distant, the Sculptor Group — home to the Silver Dollar Galaxy (NGC 253) — is sprinkled across three constellations, too dispersed to take in all at once. But similarly spread-out groups located farther away will fit in a wide-field telescope and are easier to explore at higher magnifications.

The 10 galactic gatherings highlighted below include three or more bright galaxies in the same field of view. Some are groups comparable to the Local Group, while others are dense regions within larger clusters.

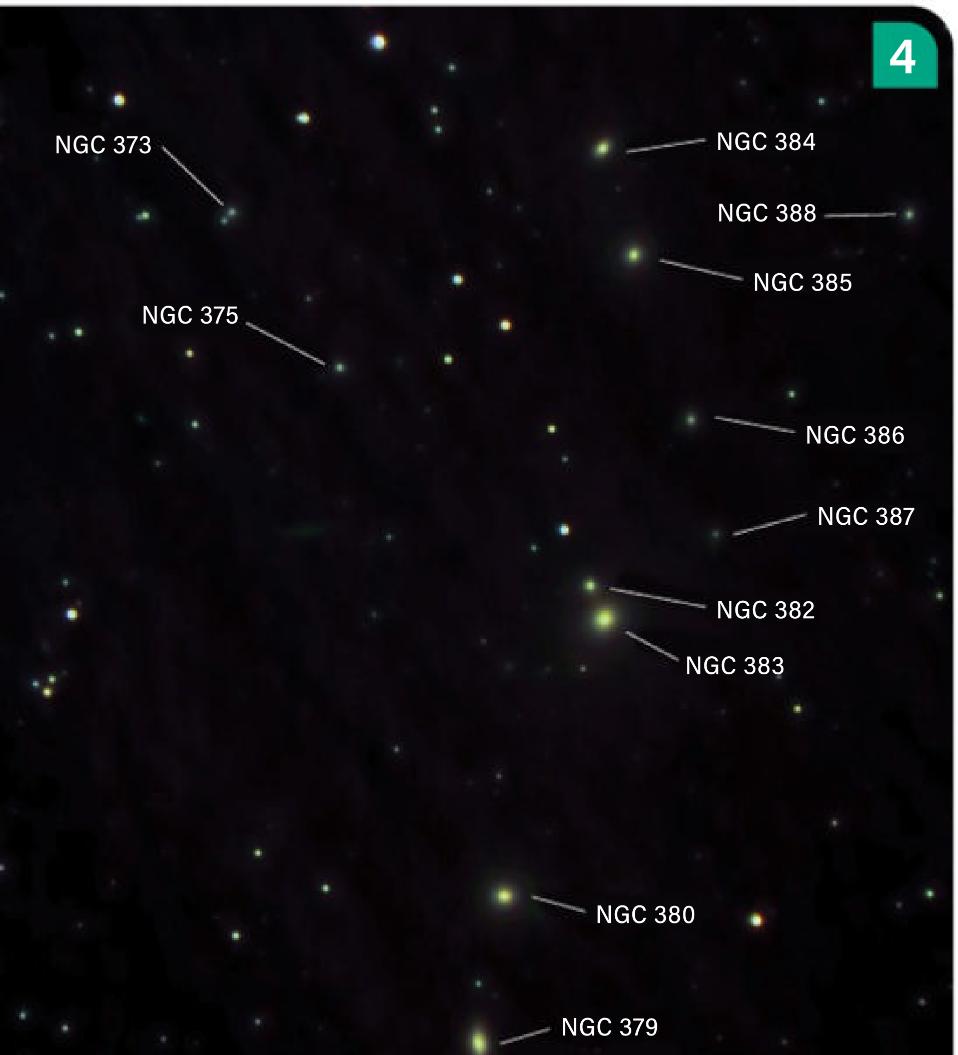
Choice galactic groupings

1 The Leo Triplet — M65, M66, and NGC 3628 — are all spiral galaxies located about 35 million light-years away. They are close enough to be seen in the same low-power telescopic field, yet far enough from one another that they are minimally interacting. M65 is magnitude 9.6, M66 is 8.9, and NGC 3628 is a deceptive 9.5. At 15' by 3.6', NGC 3628 is the largest galaxy of the triplet. Inclined edge-on and dimmed by a thick lane of light-absorbing dust, it's much harder to spot, despite its brighter magnitude. M65 (8.7' by 2.2') and M66 (8.2' by 3.9') are classified as SAB galaxies, which are intermediate galaxies that fall between normal and barred spirals.

2 M95, M96, and M105 might be called Leo's second triplet, except there are additional members in the area. M105 has two apparent neighbors: NGC 3384 and NGC 3389, located 33 million to 36 million light-years from us. M96 is an intermediate spiral that is 6.9' by 4.6' across and, at magnitude 9.2, is the brightest of the three. Nearby is M95, a magnitude 9.7 barred spiral that is 7.8' by 4.8' across. M105 is a large E1 elliptical galaxy some 2' across, glowing at magnitude 9.8; it consists of older stars with a dearth of dust. Neighboring NGC 3384 is a barred lenticular galaxy (SB0) with characteristics of both



3 MARKARIAN'S CHAIN Markarian's Chain resides in the heart of the Coma-Virgo galaxy cluster. In this image, which reveals galaxies down to about 15th magnitude, the bright galaxies M84 (farthest right) and M86 sit right of center, while M87 is visible at lower left. ALAN DYER



4 PISCES GALAXY CLOUD The Pisces Cloud (also known as Arp 331), a tiny chain of elliptical galaxies, is actually part of the Perseus-Pisces Supercluster. TOM WILDONER/CC BY-SA 4.0

6 DRACO TRIO The Draco Trio sports three galaxies with different morphologies all packed within an area half the size of the Full Moon. NGC 5985 (right) is a face-on spiral. NGC 5982 (middle) is an elliptical galaxy. NGC 5981 (left) is an edge-on spiral. These galaxies lie between 100 million and 140 million light-years from Earth. BOB FERA

elliptical (old stars, little dust and gas) and spiral (disk-shaped) galaxies. At magnitude 9.9 and 5.5' by 2.9' in size, NGC 3384 is easy to see flanking M105. Another neighbor is NGC 3389, a background Sc spiral (magnitude 12.4; 2.9' by 1.1') with a compact central hub and a diffuse disk.

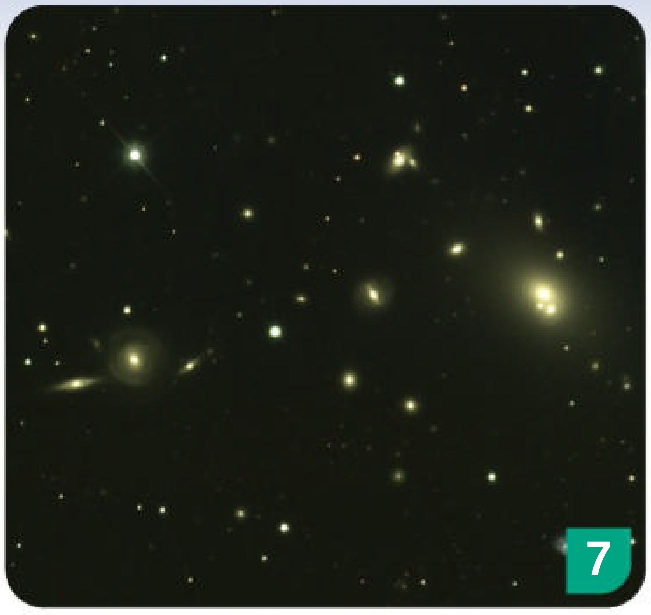
3 **Markarian's Chain** forms the core of the Virgo Cluster. Members include M84, M86, NGC 4435, NGC 4438, NGC 4458, NGC 4461, NGC 4473, and NGC 4477. This alignment of galaxies is beyond the usual reach of wide-field telescopes, as its members stretch across about 3°. However, it is possible to see several galaxies with low power. By scanning, you can sweep the entire chain. NGC 4435 and NGC 4438 are an interacting pair known as Arp 120, also called The Eyes. The fainter NGC 4435 is a barred lenticular galaxy while NGC 4438 is a larger spiral, heavily distorted with clumpy dust clouds. The apparent distortion is due to a somewhat edge-on ring of blue stars. Not part of the chain but still worth exploring are the edge-on galaxies NGC 4388, which forms the point of a triangle with M84 and M86, and NGC 4402, located north of M86. NGC 4458 and NGC 4461 form another link in the chain.

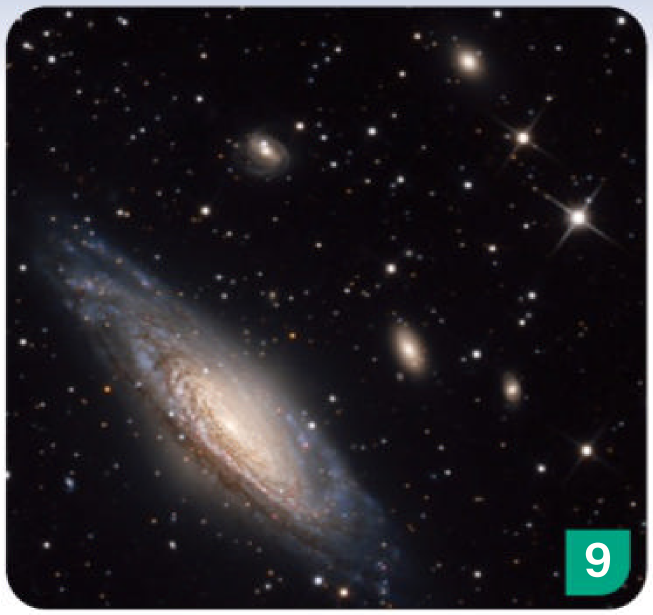
4 **The Pisces galaxy cloud** (Arp 331) is a great object for telescopes 10 inches and up. It is an apparent north-south alignment of eight galaxies: NGC 379 (magnitude 12.9), NGC 380 (12.5), NGC 382 (13.2), NGC 383 (12.4), NGC 384 (13.1), NGC 385 (13.0), NGC 386 (14.3), and NGC 387 (15). Its faintest member, NGC 387, requires a 16-inch scope. In the same field but not in the chain are NGC 373 (magnitude 13.1), NGC 375 (13.1), and NGC 388 (14.3). With so many galaxies crammed into a relatively small field, this chain is the most dazzling part of the Perseus-Pisces Supercluster.

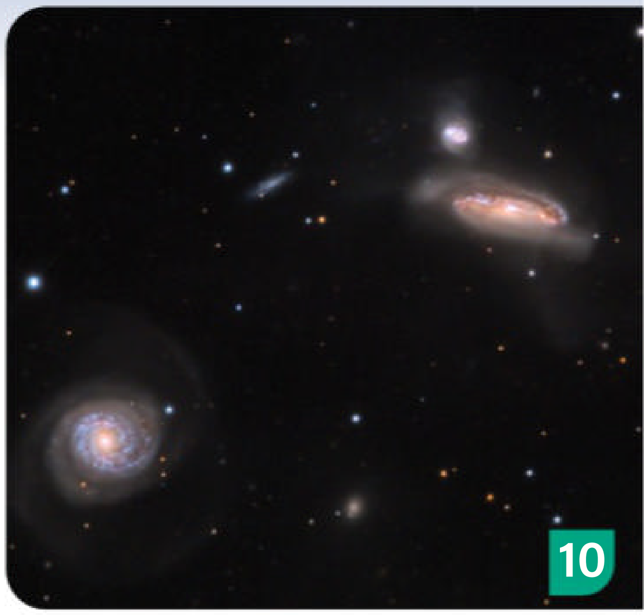
5 **The Eridanus A Group,** part of the giant Eridanus Cluster, lies between some 75 million and 180 million light-years distant. Centered around a declination of about –18°30'30", it's an easy target for mid-latitude observers. The core consists of seven early-type galaxies. NGC 1407 and NGC 1400 are class E0 ellipticals. NGC 1402, NGC 1391, and IC 343 are class SB0 barred lenticulars. NGC 1393 and NGC 1394 are regular class S0 lenticulars. The galaxies range in magnitude from 9.7 (NGC 1407) to 13.2 (NGC 1391 and IC 343), making this group easy to unlock with an 8-inch telescope under good skies. Four of the galaxies form a diamond, while the three outliers create a chain to the north — an obscure but fascinating winter target.

6 **The Draco Trio** consists of NGC 5981, NGC 5982, and NGC 5985, located some 130 million light-years away. With two spirals and an elliptical galaxy oriented at different angles, this trinity has variety. The group's brightest two members are magnitude 11.1, making them visible through modest scopes. NGC 5982 is a class E3 elliptical with a slight oval shape and sports a condensed nucleus. NGC 5985, meanwhile, with its compact central bar and ring-like spiral arms, resembles M109 (NGC 3992) in images. On the opposite side of NGC 5982 lies the edge-on spiral NGC 5981. At 13th magnitude, it can be picked up easily in an 8-inch telescope.

7 **Abell 2199** in Hercules is dominated by the cannibalistic galaxy NGC 6166. This galaxy has several nuclei, which are the leftover cores of galaxies that it gobbled up in the past. Classified as a type cD2 peculiar, such mega-galaxies are only found in galaxy clusters and may contain a trillion or more stars.







(For comparison, the Milky Way contains roughly 200 billion stars.) NGC 6166 lies some 450 million light-years away, so it appears just 2.1' by 1.7' in size. In spite of its vast distance, this magnitude 11.8 target is bright enough see in modest telescopes. With larger apertures, try to find any of the five nuclei within, designated NGC 6166 A through E. With a 12-inch or larger scope, neighboring galaxies may become visible, depending on atmospheric transparency. In 16- to 25-inch scopes, the number of galaxies in the field increases dramatically. If you are seeking a similar galaxy, track down NGC 2832 in Lynx. It forms the core of Abell 779, another major galaxy cluster.

8 **NGC 7172, NGC 7173, NGC 7174, and NGC 7176** is a great group for observers with a good southern horizon view of the "tail" of Piscis Austrinus the Southern Fish. Each member is a respectable size, ranging from 2.8' by 1.4' to 4.4' by 2.4'. And with magnitudes around 12, they can all be seen in modest telescopes if atmospheric haze is minimal. For those in the southern U.S., it's an easy group to find, residing roughly 12° west-southwest of Fomalhaut, the brightest star in that part of the sky. NGC 7173, NGC 7174, and NGC 7176 are an interacting group (Hickson 90) consisting of two ellipticals and a warped spiral galaxy that is nearly lenticular. NGC 7172 is a lenticular, type 2 Seyfert galaxy with an active nucleus surrounded by dust clouds.

9 **NGC 7331,** Pegasus' brightest galaxy, lies in the foreground of a larger gathering of galaxies. Unlike the previous selection, none of these galaxies are close to each other in space. NGC 7331, an Sb spiral galaxy, is magnitude 9.5 — brighter than many Messier objects. At 50 million light-years distant, its dimensions are a generous 10.5' by 3.5'. The background objects NGC 7335, NGC 7336, NGC 7337, and NGC 7340 are fainter (ranging from magnitude 13 to 15), smaller (1.3' across or less), and roughly six to eight times farther than NGC 7331. They are strung out from the closest, NGC 7340, an E3 elliptical galaxy about 294 million light-years away, to the farthest, NGC 7336, an Sbc spiral located about 365 million light-years away. In between are NGC 7335, a lenticular galaxy, at 332 million light-years, and NGC 7337, an SBb barred spiral some 348 million light-years distant. About half a degree southwest of NGC 7331 lies the famous Stephan's Quintet, a favorite galaxy group of many observers. The only reason it's not on this list is because it's on so many others!

10 **NGC 7769, NGC 7770, and NGC 7771** form another interesting group in Pegasus that is located some 200 million light-years away. This target flies under many observers' radar, often overshadowed by the galaxy groups mentioned in the previous entry. Nonetheless, it's a cool collection of galaxies to explore. NGC 7769 is a 12th-magnitude Sb face-on spiral (1.6' across) with a dazzling nucleus. NGC 7771 is a magnitude 12.2 SBb barred spiral that is highly inclined and just 2.3' by 1.1' across. It is interacting with NGC 7770, a compact, distorted spiral galaxy that deep photographs reveal is comma-shaped with an offset nucleus. At magnitude 13.8, a 12-inch or larger scope may be required to unlock it. Observing these two is to look upon a freeze-frame of a galactic ballet, with one galaxy in the throes of merging with another. The third member of the trio, NGC 7769, is also an interacting part of this group. Markarian 331, a background magnitude 13.9 SBb galaxy to the north, may be seen with a 12- to 14-inch telescope under good skies. All in all, this is a busy group! Deep astroimages may also reveal a filigree of dust clouds throughout the field above the Milky Way's galactic plane.

The next clear night, get out there and see how many galaxies you can observe — it doesn't take a group effort! ◆

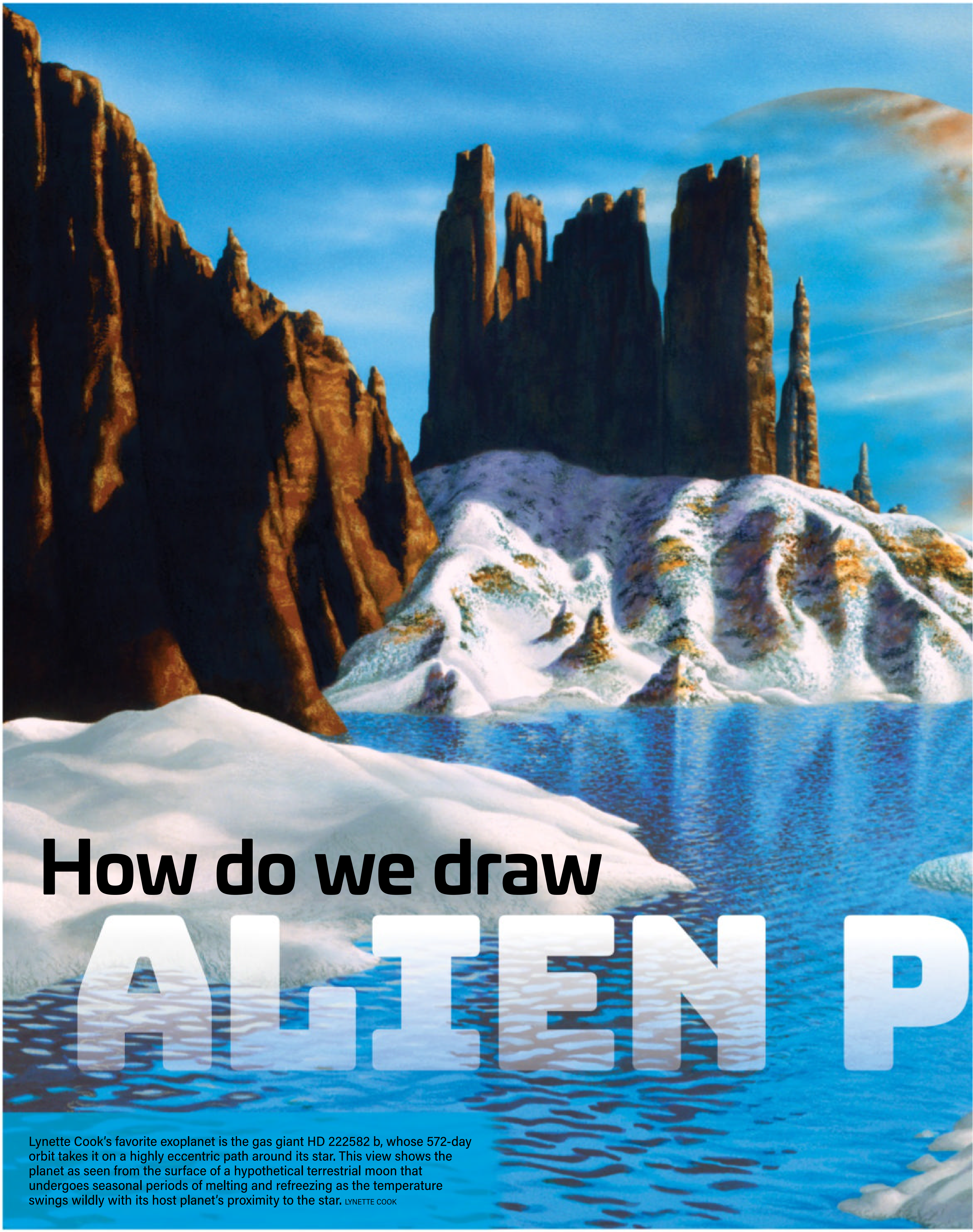
7 **ABELL 2199** NGC 6166 (right) features multiple nuclei — the remains of other galaxies in the cluster that it has merged with over time. ADAM BLOCK/NOAO/AURA/NSF

9 **NGC 7331** NGC 7331 looms in the foreground of this scene; the four other galaxies are many times more distant. SERGEY TRUDOLYUBOV

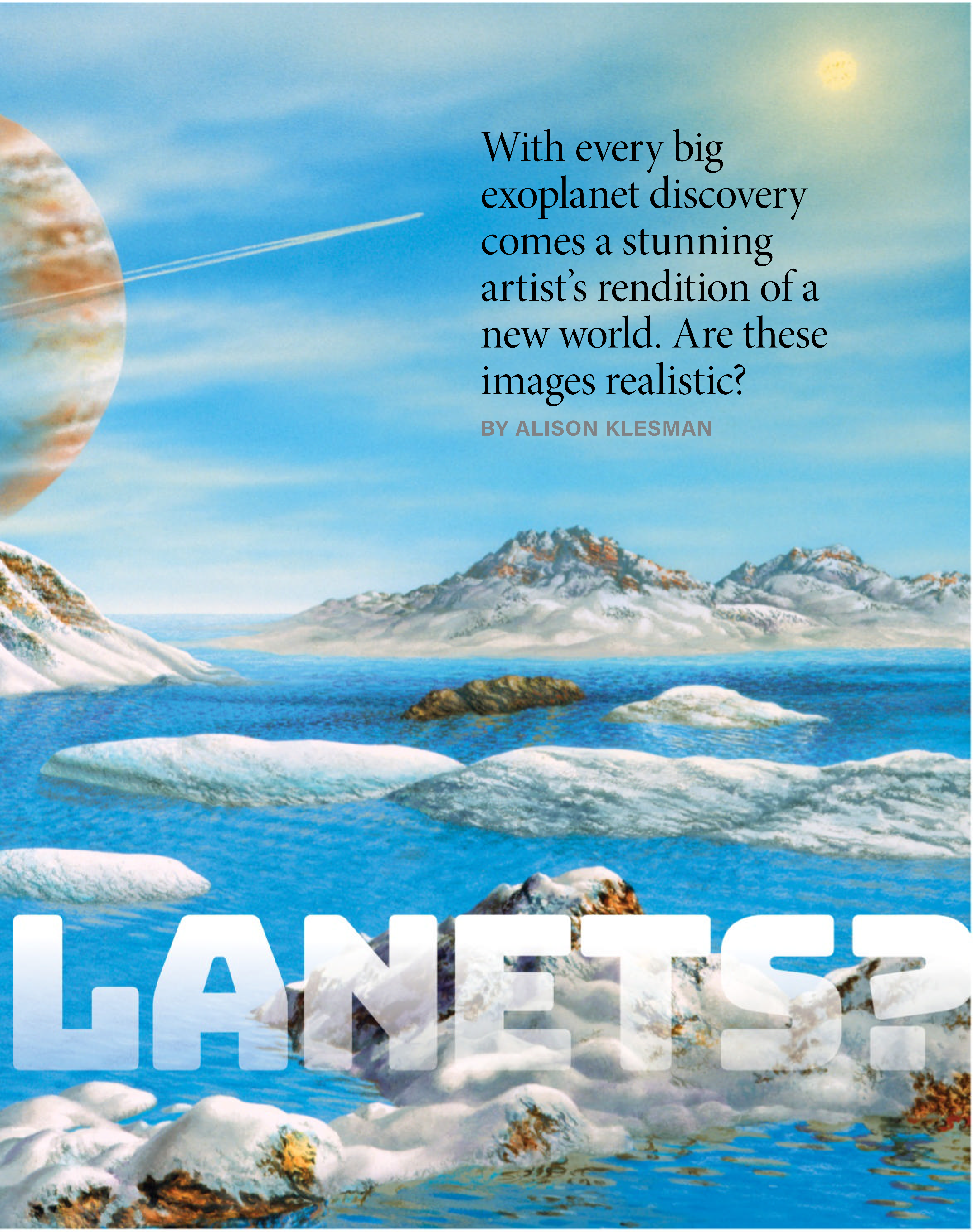
10 **NGC 7769, NGC 7770, AND NGC 7771** Spiral galaxy NGC 7769 (lower left) presents itself face-on, while barred spiral NGC 7771 (upper right) is highly inclined. Just above the latter is the compact companion galaxy NGC 7770. ADAM BLOCK/MOUNT LEMMON SKY CENTER/UNIVERSITY OF ARIZONA

Alan Goldstein, *a longtime contributor to Astronomy, dedicates this article to his wife, Debbie, who passed away last year during its writing.*

How do we draw ALIEN P



Lynette Cook's favorite exoplanet is the gas giant HD 222582 b, whose 572-day orbit takes it on a highly eccentric path around its star. This view shows the planet as seen from the surface of a hypothetical terrestrial moon that undergoes seasonal periods of melting and refreezing as the temperature swings wildly with its host planet's proximity to the star. LYNETTE COOK



LANETS?

With every big exoplanet discovery comes a stunning artist's rendition of a new world. Are these images realistic?

BY ALISON KLESMAN

ASTRONOMICAL WEBSITES AND PRESS RELEASES brim with pictures of swirling gas giants, watery terrestrial worlds, and strange planetary systems with exotic suns. But just how realistic are these artist's concepts? Do they truly show newly discovered worlds, or are they simply fanciful pictures meant to draw you into reading about the latest addition to the exoplanetary menagerie?

The process

"These aren't just people slapping up a new exoplanet template every time that one is discovered. This is a real depiction, if we can have one," says prominent exoplanet artist Lynette Cook, who has been illustrating other worlds since 1995. "It's based on scientific fact, as far as the facts go that we have. And then beyond that, it's fact-based theory." Even when artistic license is involved — which it often is — "it is at least within the boundaries of what seems plausible," she says.

But how do we even know what's plausible? Illustrating an extrasolar world for a publication or press release, Cook says, starts and ends with conversations. The artist works closely with researchers to learn as much as possible about the planet or system they've been tasked with depicting. The researchers may start by providing information about the star — such as age, mass, and type (a proxy for temperature) — as well as the mass and distance of the planet.

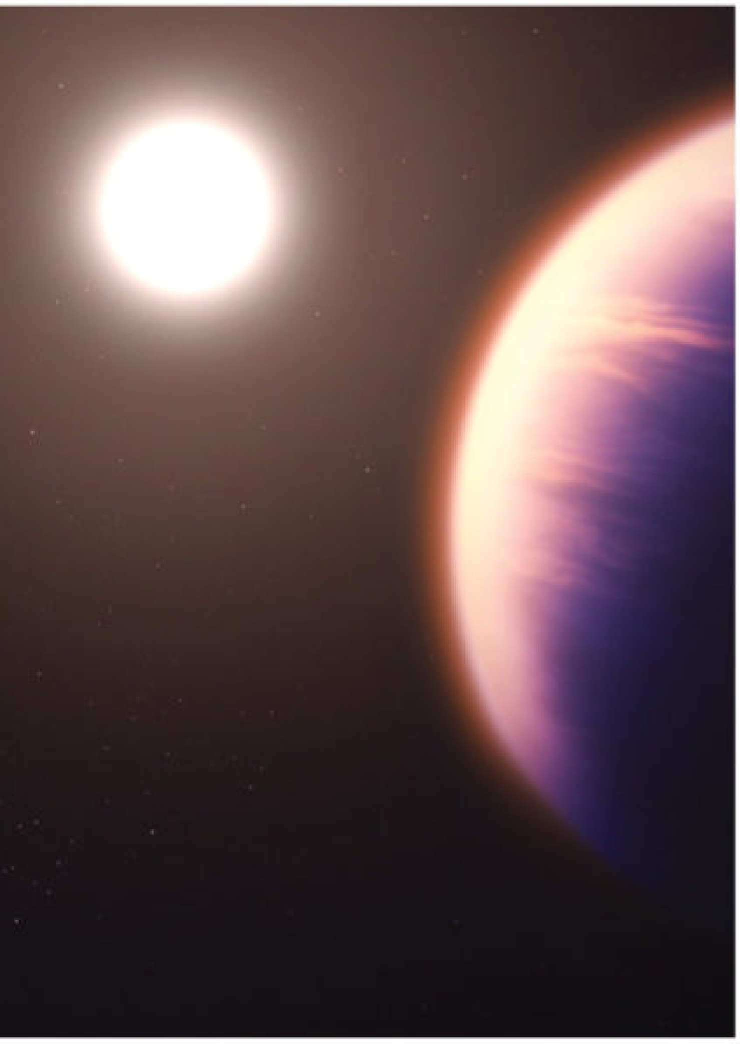
That may seem like only a basic framework, but hidden within these few numbers is a wealth of information. Stars with different temperatures put out their maximum light at different colors — cool stars are red, middling stars are orange-yellow, hot stars are blue — so the star's type tells the artist its color. Its age determines whether it might have few or many starspots (what we call sunspots on the Sun) as well as how active it's likely to be. A planet's mass dictates whether it is terrestrial or gassy, while its distance informs the size its sun appears in its sky and whether the world sits in the habitable zone, and thus whether surface water is liquid or ice (or likely not present at all). And tidally locked planets — those with one side permanently facing

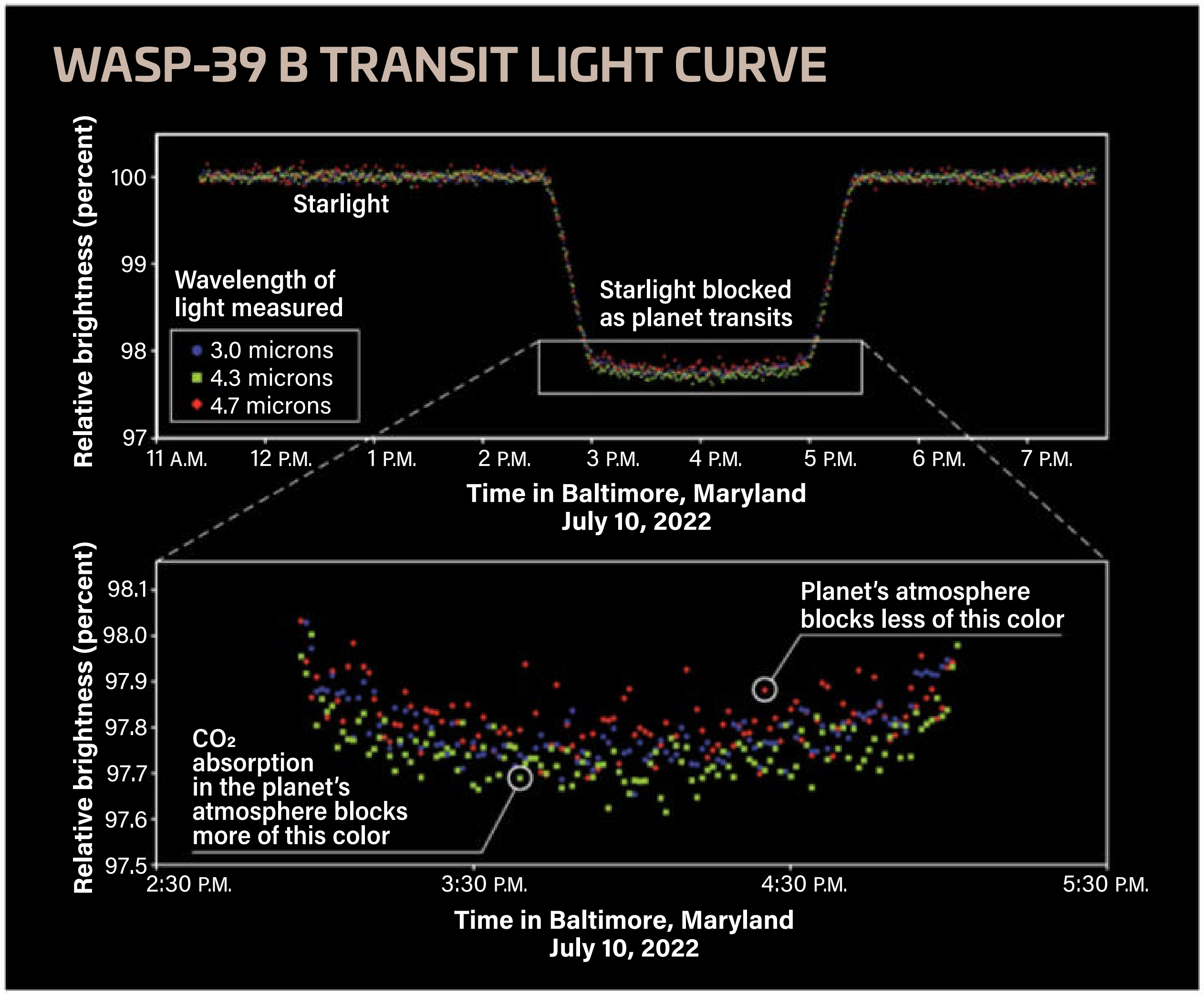
ART AS HISTORY

"ASTRONOMICAL PAINTINGS ARE OUR BEST RECORD of what human beings thought other worlds were like, during different decades," William Hartmann says — better even than scientific journals, where findings are published piecemeal as individual papers over time. "Scientists tend to be trained in one technique and so we have articles on one aspect at a time: spectroscopy through telescopes, computer models of orbit evolution, meteorology of atmospheres, geochemistry, petrology of rock samples, etc.," he says. But to paint an alien landscape and sky, artists must combine all these details to create a complete picture of how we understand such places might appear, based on the available information at the time.

Which is why, he adds, "I tell museum curators, 'If you have older astronomical paintings that are 'incorrect' according to current knowledge, for heaven's sake, don't throw them out!'" —*A.K.*

↓ This artist's concept (below) of the tidally locked gas giant WASP-39 b was developed in part from a transmission spectrum taken by the James Webb Space Telescope (below right) as the planet transited its star. The data show evidence of carbon dioxide in the atmosphere; other telescopes have found water vapor, sodium, and potassium. Astronomers believe the planet has clouds but no Jupiter-like bands. BELOW: NASA, ESA, CSA, JOSEPH OLMSTED (STSCI). GRAPHS: *ASTRONOMY*: KELLIE JAEGER, AFTER NASA, ESA, CSA, LEAH HUSTAK (STSCI), JOSEPH OLMSTED (STSCI)




WASP-39 B TRANSIT LIGHT CURVE
Relative brightness (percent)
100
99
98
97
Starlight
Wavelength of light measured
● 3.0 microns
● 4.3 microns
● 4.7 microns
Starlight blocked as planet transits
11 A.M.
12 P.M.
1 P.M.
2 P.M.
3 P.M.
4 P.M.
5 P.M.
6 P.M.
7 P.M.
Time in Baltimore, Maryland
July 10, 2022
Relative brightness (percent)
98.1
98.0
97.9
97.8
97.7
97.6
97.5
Planet's atmosphere blocks less of this color
CO₂ absorption in the planet's atmosphere blocks more of this color
2:30 P.M.
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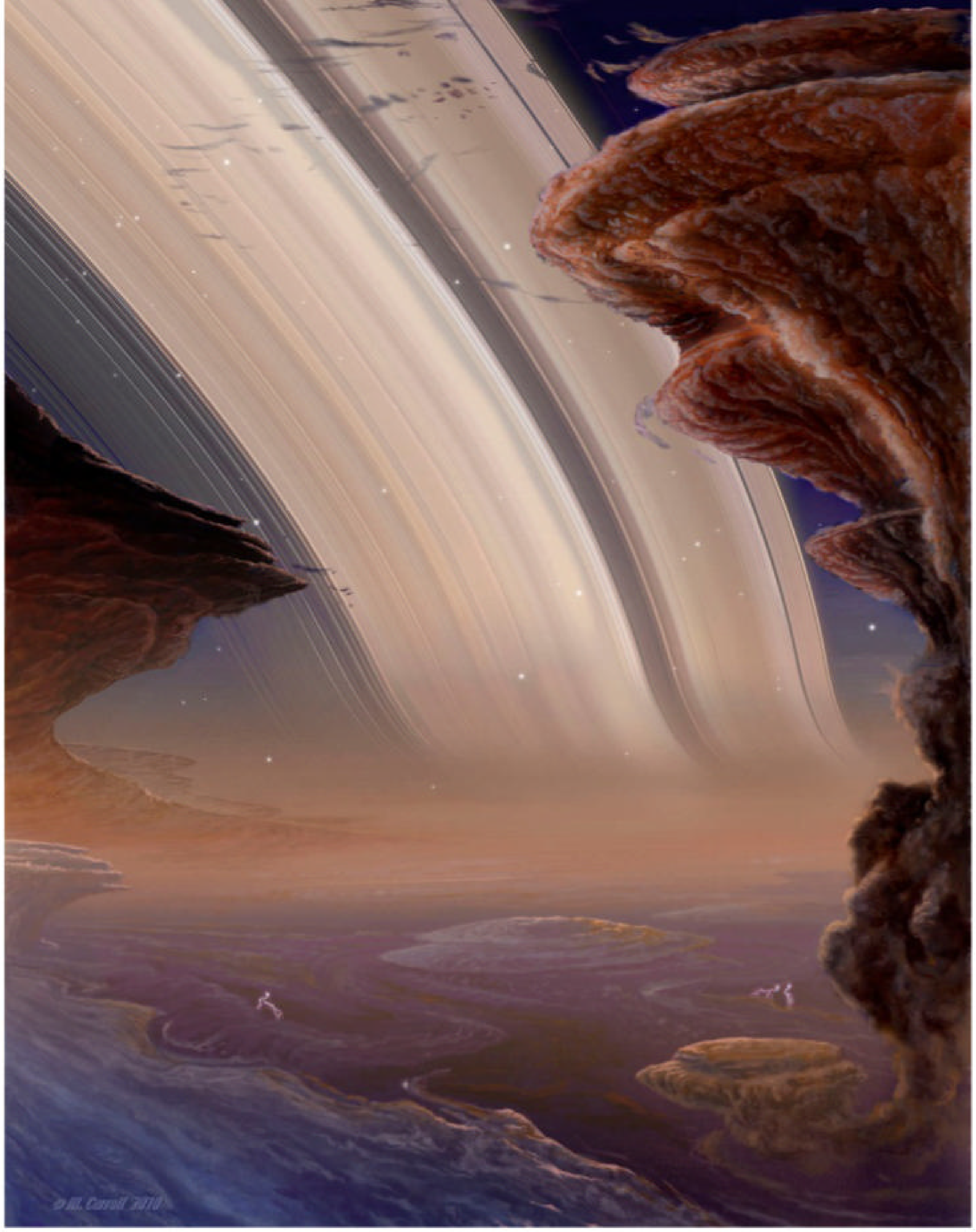
4:30 P.M.
5:30 P.M.
Time in Baltimore, Maryland
July 10, 2022



Beyond the towering clouds of a saturnian evening, passing moons trundle back and forth. The spectacular rings seem to bend as the light passes through denser air toward the horizon. MICHAEL CARROLL

their star — can have vastly different features than those that are not.

Astronomical artists take these seemingly disparate bits of scientific data and "synthesize all those aspects to show us what it would be like to be in those places," says William Hartmann, a noted planetary scientist and artist who has been envisioning planets around other stars since before any had been discovered.

Often, the artist will make several mock-ups, going back and forth with the researchers to determine which is best and any details that might need adjustment, Cook says. After all, many planets look similar, so it is typically the small details that differentiate one from another.

Those details increasingly require less guesswork. Watching the way light filters through an exoplanet's atmosphere as the planet crosses in front of its star can reveal the structure and chemical composition of otherworldly atmospheres. The presence of certain molecules can dictate the color the planet might appear — red and tan like Jupiter, blue like Neptune, or perhaps a hue absent from our own solar system altogether, such as purple or pink.

And some researchers are modeling the surfaces and climates of exoworlds, showing what distant planets could look like based on different scenarios. By tweaking factors such as ocean salinity and atmospheric composition on a watery world, for example, such models can produce simulated, generic global maps of ocean, land, and ice, which artists can then turn into a stunningly realistic — and scientifically plausible — image.

> **"SCALE IS THE HARD THING TO COMMUNICATE … YOU DON'T HAVE THOSE VISUAL CUES THAT WE DO IN NATURE HERE."** *— Michael Carroll*

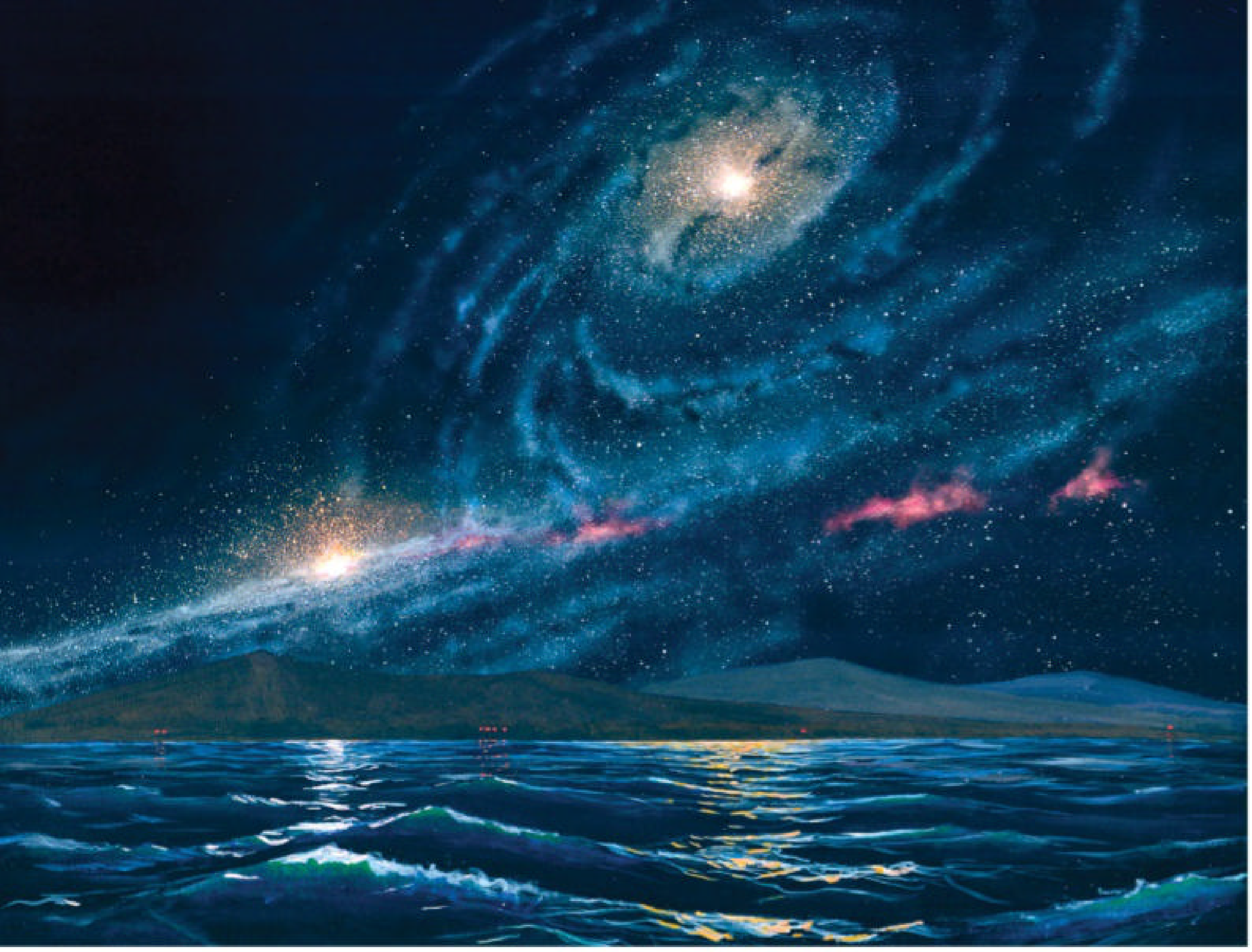
Artistic license

With these details in hand, an artist can go about creating a compelling exoplanet surface view. For Hartmann, two things are most important: "What interesting things might be seen in the sky, and what sort of surface do we want to depict?" He likes to imagine views from planets in star systems and situations unlike our own — for example, he says, a planet whose central star has been thrown out of its parent galaxy during a galactic merger.

Regardless of the view, one of the most challenging concepts to communicate in alien landscapes is a sense of scale, says longtime science writer and illustrator Michael Carroll, whose art often includes the worlds of our own solar system as well as those beyond. Sometimes a planet, moon, or asteroid doesn't have an atmosphere, "so you don't have those visual cues that we do in nature here." But even then, "you can fake it a little bit" for the sake of providing a familiar perspective the audience can connect with, he says.

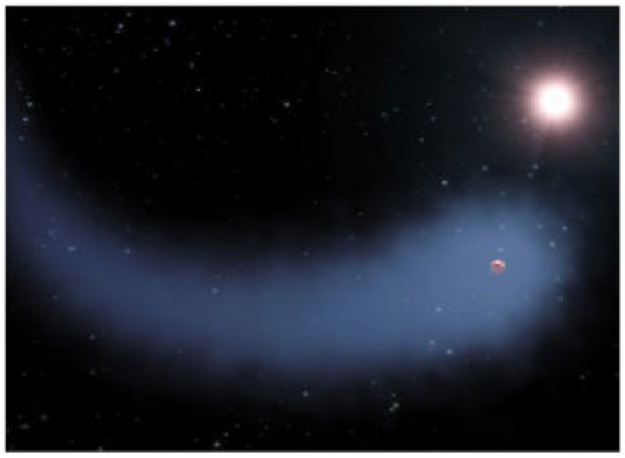
After all, these stunning illustrations are meant to educate. "The astronomical artist builds a bridge between that abstract pile of information and something that an untrained person can understand," Carroll says.

Cook agrees that sometimes a bit of artistic license is called for — and vital. For example, when showing an entire system of planets from the perspective of a distant ice giant, the innermost planets near the host star would simply look like tiny dots, rather than visible spheres. But, she argues, such a realistic depiction would confuse the general public. A layperson might have trouble finding those inner planets among the background stars. "So, I would make [the inner planet] a little tiny circle," she says. "Now, that's artistic license, but it's also part of the education process."



This 1996 painting shows the view from a hypothetical exoplanet whose central star was ejected from its parent galaxy during an interaction with another galaxy, both of which loom large in the sky. Though no such planet has been found, these events do generate forces that can send stars into intergalactic space. WILLIAM HARTMANN

Neptune-sized Gliese 436 b is so close to its bright parent star that the planet's atmosphere is evaporating away, leaving a cometlike tail trailing behind the planet, as depicted in this artist's rendering. NASA, ESA, STSCI, AND G. BACON



"WHAT INTERESTING THINGS MIGHT BE SEEN IN THE SKY, AND WHAT SORT OF SURFACE DO WE WANT TO DEPICT?" *— William Hartmann*

In some cases, Cook adds, she's given more latitude, such as setting the view of a known gas giant on the surface of a hypothetical moon to "put this really gorgeous landscape in the foreground … so it's all gorgeous and you feel like you're standing on it."

In other cases, researchers might only want to show what is known and nothing else, which can present its own kind of challenge. "If you've just got a gas giant, then it's a matter of, how do I make it look different from all the gas giants that I've already painted?" she says. "It has to look like the thing it is, but you don't want to just totally recreate the same thing over and over again, so that becomes more of an artistic challenge rather than a scientific challenge."

Ultimately, it's about not only educating, but also about creating something new, Carroll says: "You can do a diagram, you can do a painting that shows everything just great and is totally uninspired. Or you can try to bring a little bit of beauty into the world."

Similar but different

In the decades since the first discovery of an extrasolar planet in 1992, the field has veritably exploded, with more than 5,000 confirmed planets known today.

Still, many images found in news stories or press releases look similar. And it's not despite the deluge of scientific data; it's because of it. Although astronomers are still hashing out the details, we do know that the overall process of building planets is remarkably uniform throughout the galaxy: All planets seem to form from the disk of debris left over after their parent star has ignited, though even tiny variances can render vastly different planets and systems over time.

That means our own solar system often serves as a jumping-off point. For example, ice crystals still form even in low- or no-pressure conditions, and features like dunes can be found across the solar system, on planets, dwarf planets, and even comets. "You have to be careful with analogues," Carroll says, "but they're really the backbone of what informs us as to what these exotic worlds will look like."

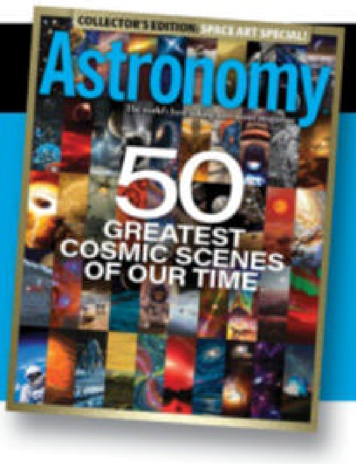
And some might be truly exotic. In lower gravity, "a tower of ice can be five times as tall," Carroll points out. Or, Hartmann says, "a red and blue pair of stars in a double star system would create shadows in different colors. The shadow cast by the red star would get only light from the blue star, hence be bluish, and vice versa."

With so many planets known, and more to come, there are plenty of options, both exotic and familiar. So although each illustration comes from the imagination of an artist, it is an informed, careful depiction of what could be reality that is designed to both educate and inspire.

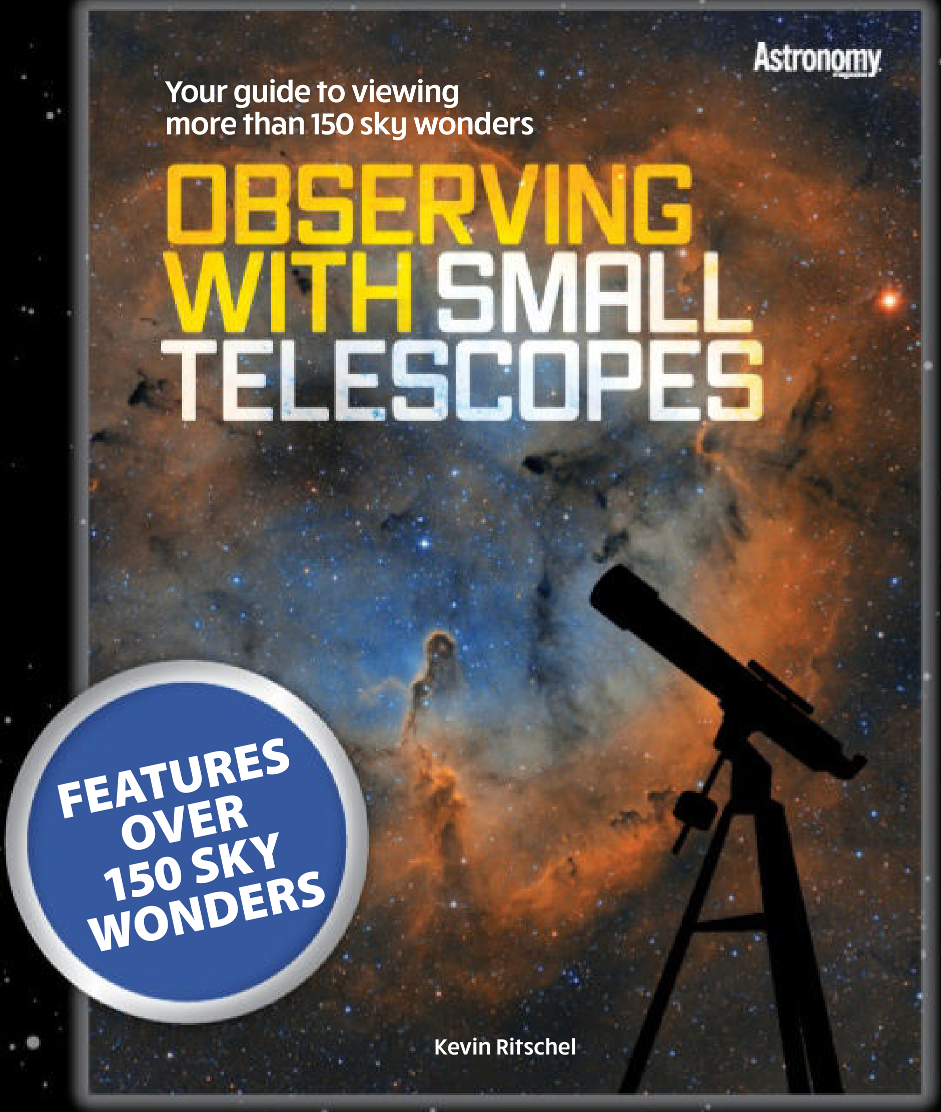
Alison Klesman *is senior editor of* Astronomy *and is fascinated by the artistic process, though she herself is unable to draw so much as a non-lumpy circle.*

MORE ASTRONOMY ART

THE JULY 2022 ISSUE of *Astronomy* is a special collector's edition featuring an inside look at the space art genre, written by prominent artists including William Hartmann. Inside, you'll find an exclusive gallery of space art not collected anywhere else. You can purchase a copy today at www.myscienceshop.com/product/ASY220701-C.



YOUR GUIDE TO VIEWING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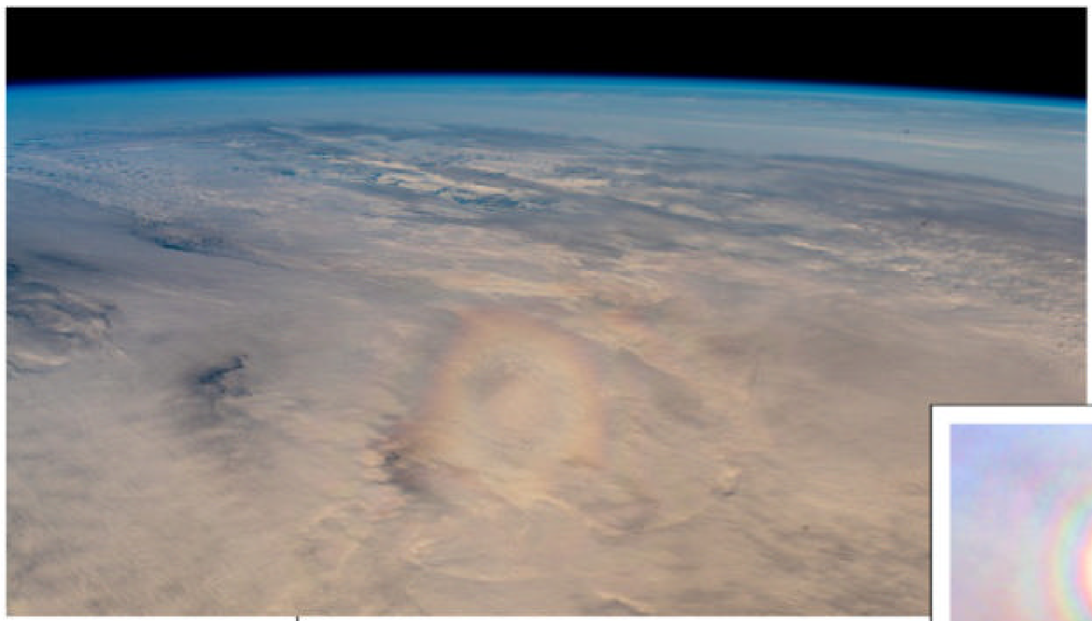
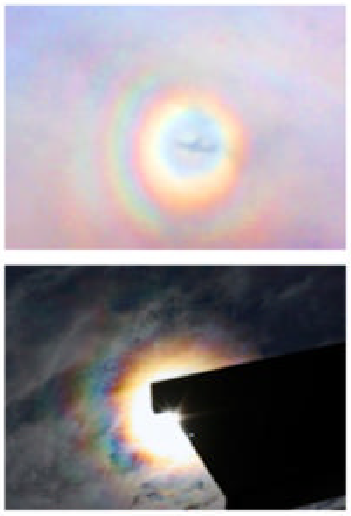


ABOVE: European Space Agency astronaut Alexander Gerst captured this glory on Sept. 14, 2018, while aboard the International Space Station. ESA/A. GERST CC BY-SA 3.0 IGO



CENTER: The glory (top) and an atmospheric corona (bottom) appear similar, but the glory appears when looking away from the Sun, not at it. STEPHEN JAMES O'MEARA (2)

The next time you fly, be sure to secure a window seat opposite the Sun — and pray for clouds. Under the right conditions, you just might see a glorious atmospheric phenomenon known as, well, *the glory*.

The glory is an optical effect that appears as a series of concentric colored rings on clouds or mist. In shape and color, it resembles the Sun's atmospheric corona, and both are caused by the interplay of light and water suspended in the atmosphere — either as tiny water droplets or ice crystals. But unlike the corona, the glory appears opposite the Sun, at the antisolar point. Since you look away from the Sun to see the glory, it is more comfortable to observe than the Sun's corona.

There are other differences as well. The glory's central aureole — its bluish inner disk — is not as intense as the corona's, making it appear more defined. And while the order of colored rings (blue on the inside, red on the outside) is similar for both, the glory's outer rings are usually easier to detect. In fact, it is not uncommon to see three or more sets of colored rings in the glory. This is rare with coronae, especially if the droplets causing them are all the same size, as tends to be the case in freshly condensed clouds or mist.

Glories are a complex and not-yet-fully-understood affair.

Coronae are produced by light diffracting around the edges of water droplets or ice crystals. Glories, however, are a more complex and not-yet-fully-understood affair. Although Maxwell's equations of electromagnetism can describe the pattern of rings when water droplets scatter light from the antisolar point back to your eyes, they do not explain *how*. The problem is that water does not refract light by the correct amount to achieve the required scattering angle of about 180°, even if a ray reflects off the inside of a droplet multiple times.

In the Sept. 20, 2005, issue of *Applied Optics*, optics researcher Philip Laven offered an explanation based on the possibility that light can propagate along the surface of a droplet. (Polarized radio transmissions can similarly propagate along the ground.) This means that light rays entering at the edge of a water droplet could repeatedly travel as a surface wave for a short distance before bouncing back into the droplet, allowing the rays to exit the droplet in the direction from which they came. The colored rings of the glory, then, are an interference effect between "rays entering the droplets at diametrically opposite points."

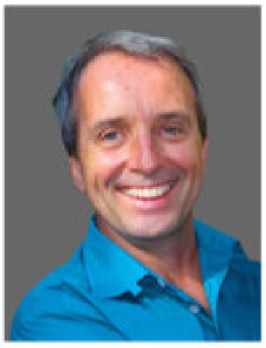
The view from above

You don't have to be on an aircraft to see the glory. Many people atop mountains have observed them against hillside clouds or fog at lower elevations. But those seen while flying in a plane are the most animated. Since the glory appears at the antisolar point from the perspective of the observer, if you sit in the back of a plane, the glory will be centered on the craft's tail end. Walk down the aisle, and you can watch the glory follow your path in the plane's shadow.

The glory's size and appearance may also change as the craft passes over clouds containing water droplets of different sizes. Like atmospheric coronae, the glory's angular extent is inversely proportional to the size of the water droplets causing it: The larger the water droplet, the smaller the glory, and vice versa. With large water droplets — say, 40 microns — the first-order ring will have a radius of about 1°. With water droplets a quarter that size, the first-order ring will have a radius nearly five times larger.

And while the aircraft's shadow has no influence whatsoever on the glory's shape, size, or color, we can see it shrink or swell against the glory, depending on how close the clouds are to the craft. The farther away from the cloud deck, the smaller the craft's shadow, and vice versa.

Despite Laven's confidence in his interpretation of what causes the glory, there is still uncertainty. As always, send your observations (and interpretations) to sjomeara31@gmail.com.



BY STEPHEN JAMES O'MEARA
Stephen is a globe-trotting observer who is always looking for the next great celestial event.

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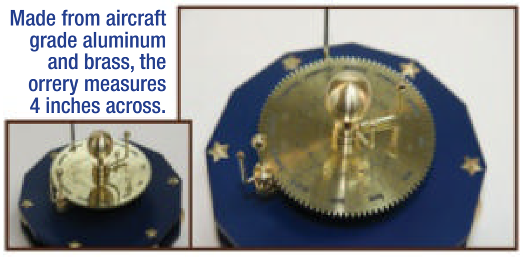

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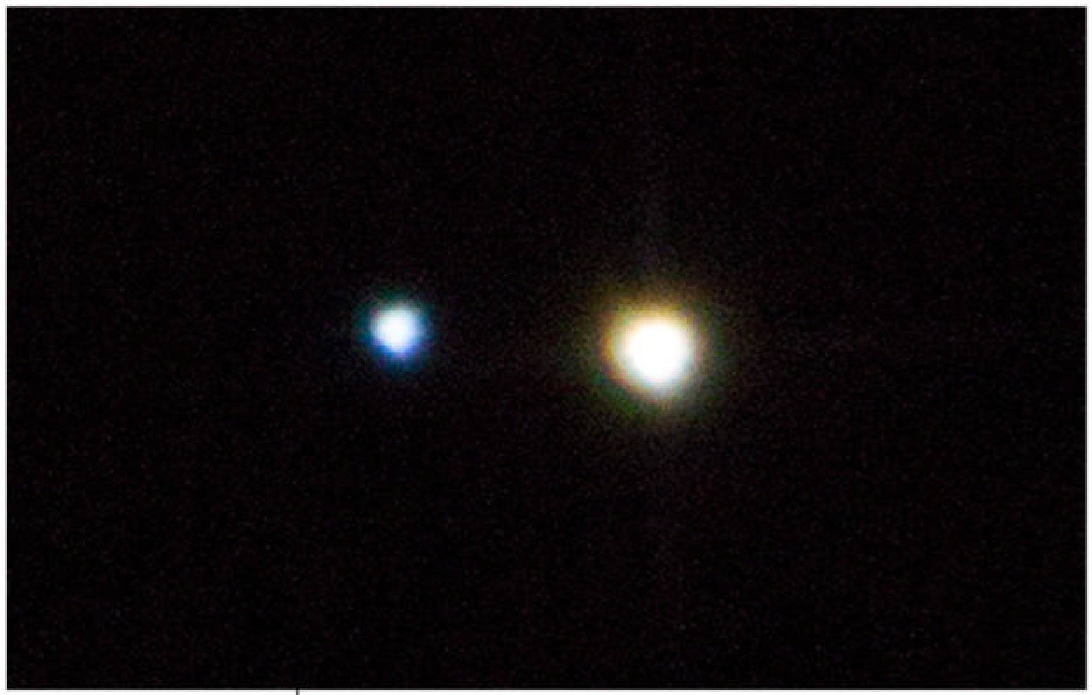
Double duty

Pair up these stellar companions this spring.



Iota (ι) Cancri, known for its blue and yellow colors, is one of the many binary stars visible this spring.
JEFFREY FISHER/WIKIMEDIA COMMONS

BY PHIL HARRINGTON
Phil received the Walter Scott Houston Award at Stellafane 2018 for his lifelong work promoting and teaching astronomy.

For many of us, light pollution has robbed our skies of once readily visible objects. That's why many residential observers have turned away from nebulae and galaxies to pursue other targets, such as double stars.

This month, let's enjoy a few of my favorite springtime binocular binaries.

We begin with a challenging binocular target, **Iota (ι) Cancri**. Often described as the Spring Albireo for its colorful yellow and blue components, Iota's two stars shine at magnitudes 4.0 and 6.6. But they are only separated by 30". That's a little too close to resolve with handheld 10x50 binoculars, but doable if they are supported on a mount. Iota can also be split in two with an image-stabilized 10x binocular and is lovely through 16x70s.

Now head to the constellation Leo the Lion. From the triangle marking Leo's hindquarters and tail, follow an imaginary line southward from Chertan (Theta [θ] Leonis) to 4th-magnitude Iota Leonis and then to Sigma (σ) Leonis. From Sigma, look for a four-star arc just 6° (about a field) southeast. The brightest star in the arc is 5th-magnitude **Tau (τ) Leonis**. Tau forms a wide binary star with a magnitude 7.5 companion 1.5' to its south. In his 1909 book *In Starland With a Three-Inch Telescope*, William T. Olcott described the appearance as "lemon and light blue." If you defocus your binoculars, you may get a hint of those colors.

Olcott also mentioned a "second pair in the field." He was referring to **83 Leonis**, just 20' northwest of Tau. It's paired with an 8th-magnitude star 14" southeast. Although potentially challenging, it can be accomplished with 10x binoculars.

But by shifting Tau toward the northwest corner of your view, you'll find three easier doubles arranged in an X-shaped asterism known as the **Double Cross**.

East of Leo, the faint constellation Coma Berenices is home to the Coma Star Cluster (Melotte 111). Swing your binoculars to the two beautiful binaries within. First, there's 5th-magnitude **12 Comae**, which is joined by a 9th-magnitude field star 60" to the southeast. If your 10x binoculars are steadily supported, splitting the pair is possible; higher-power lenses divide them easily, offering a hint of 12's yellowish tint.

The second duo in the Coma Cluster is **17 Comae**. Here, we find a 5th-magnitude primary sun accompanied by a 7th-magnitude companion 145" to its west-southwest. Both appear pure white and are easy to split.

Nestled below the bowl and handle of the Big Dipper is the faint constellation Canes Venatici the Hunting Dogs. The dogs' brightest star, 3rd-magnitude Cor Caroli (Alpha [α] Canum Venaticorum), lies about halfway between Phecda (Gamma [γ] Ursae Majoris) in the Big Dipper's bowl and Arcturus (Alpha Boötis). Once you find Cor Caroli, itself a binary star suitable for 20x and higher binoculars, look to its northeast. You should be able to see **17 Canum Venaticorum,** a pretty pairing of 6th-magnitude white suns separated by 276".

Aim 5° northwest of Cor Caroli for the Hunting Dogs' second-brightest star, Chara (Beta [β] Canum Venaticorum). By extending the line connecting the two another 6° west-northwest, you'll come to 5th-magnitude **67 Ursae Majoris**. One look will show that 67 is not alone, but rather is accompanied by three friends. The white primary star is joined by a yellow 7th-magnitude secondary star 5' to the east-northeast. A third golden 9th-magnitude companion is found 6' west of 67, while the fourth star, a 9th-magnitude pale yellow point, is 15' northeast of the primary. Detecting the subtle colors will likely take at least 70mm or 80mm binoculars.

This month, let's enjoy a few of my favorite springtime binocular binaries.

If this survey piqued your interest in observing double and multiple stars, point your internet browser to the Astronomical League's Binocular Double Star Observing Program at www.astroleague.org. Membership is required to earn a certificate of completion, but anyone can enjoy their list of 120 binocular targets.

Have a favorite double star that you'd like me to mention in a future column? Contact me through my website, philharrington.net. Until next month, remember that two eyes are better than one.

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Space tales

Kennedy Space Center Visitor Complex/Monlove

Cape Canaveral, FL

Combining the beloved characters of the *Peanuts* comic strip with stories of space, *All Systems Are Go* is a unique experience coming this spring to the Kennedy Space Center Visitor Complex. Monlove, a production company out of Montreal, will present the history of NASA using life-sized puppets of Snoopy, Charlie Brown, Linus, and more, with a laser light show and an original musical score. The gang will also talk about the Artemis missions and look ahead to future NASA projects.

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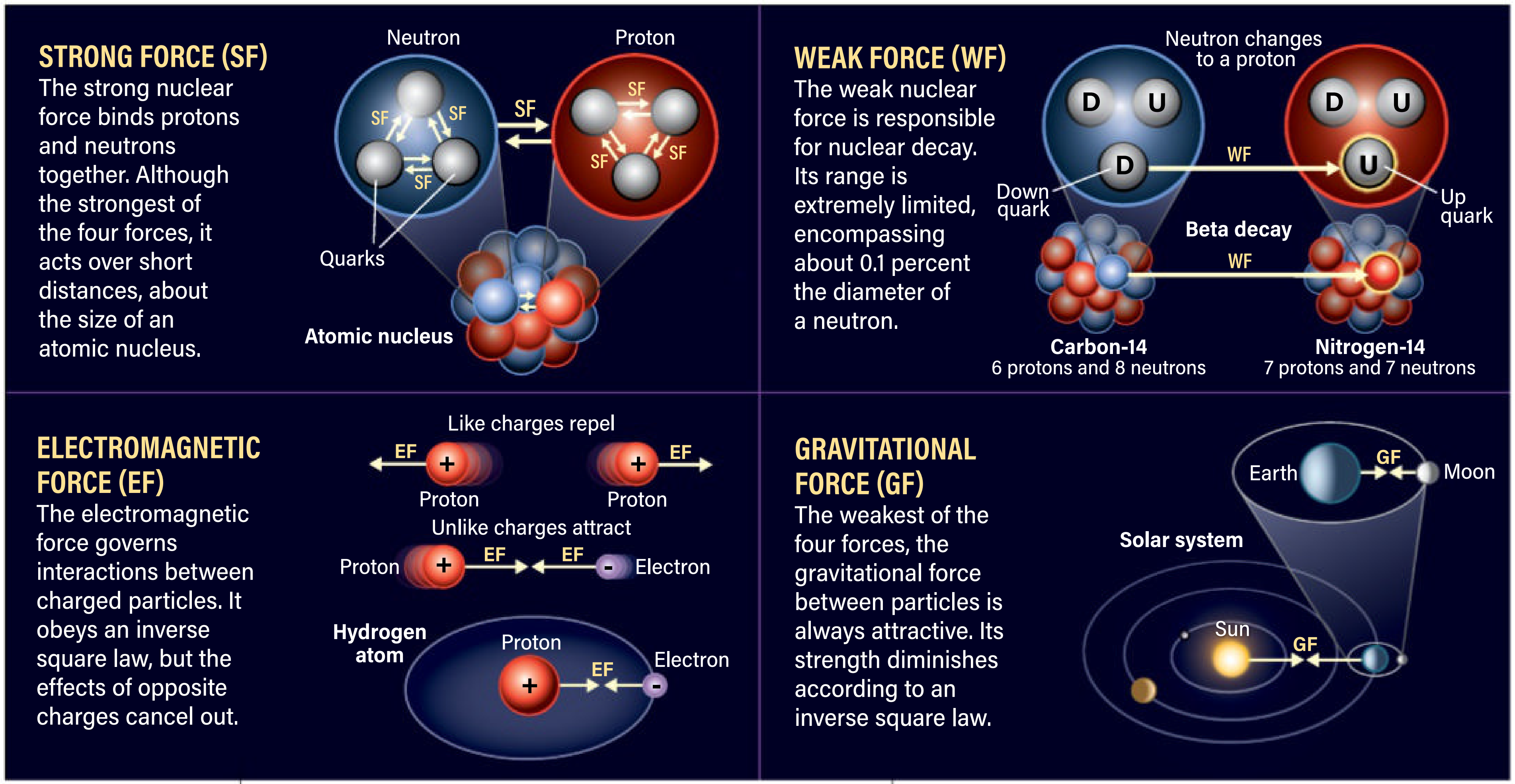


STRONG FORCE (SF)
The strong nuclear force binds protons and neutrons together. Although the strongest of the four forces, it acts over short distances, about the size of an atomic nucleus.

WEAK FORCE (WF)
The weak nuclear force is responsible for nuclear decay. Its range is extremely limited, encompassing about 0.1 percent the diameter of a neutron.

ELECTROMAGNETIC FORCE (EF)
The electromagnetic force governs interactions between charged particles. It obeys an inverse square law, but the effects of opposite charges cancel out.

GRAVITATIONAL FORCE (GF)
The weakest of the four forces, the gravitational force between particles is always attractive. Its strength diminishes according to an inverse square law.

Of the four fundamental forces, gravity is the weakest — but also the farthest-reaching.
ASTRONOMY: ROEN KELLY

Fundamental forces

Q | IF GRAVITY IS THE WEAKEST OF THE FOUR FUNDAMENTAL FORCES, HOW CAN THE SUN'S GRAVITY AFFECT DISTANT AND LOW-MASS OBJECTS SUCH AS THOSE IN THE KUIPER BELT AND OORT CLOUD?

Neal Attinson
Sonoma, California

A | It is true that gravity is weakest among the fundamental forces. However, the effect of gravity can be felt even at arbitrarily large distances for two reasons. The first is a consequence of the inverse square nature of the gravitational interaction, meaning the force of gravity diminishes with $1/R^2$, where R is the distance between two objects. But we must consider this alongside gravity's flux, which is defined as the number of force field lines (which relates to its strength) crossing a surface area.

Let's think of an imaginary sphere with the Sun at the center. The surface area of the sphere increases as the square of the distance from the Sun where the sphere is drawn. So, while the gravitational force is inversely proportional to the square of the distance from the Sun, its flux — which is a product of this force and the surface area — remains constant no matter how large one imagines the sphere because the distance terms cancel out. This constant flux is the reason for the long-range effect felt at arbitrarily large distances.

This is not true in the case of, say, the strong nuclear force, which is several orders of magnitude stronger but whose influence falls sharply compared to the inverse square and so does not have a constant flux. Hence, it is short ranged, limited to the length scales of atomic nuclei.

The second part of the answer is that gravity cannot be screened. Think about how we can draw window shades if it's too bright outside, or how the metal mesh on your kitchen microwave door keeps the microwaves inside. We cannot do something like that to block gravity. Therefore, intervening matter between the Sun and distant objects doesn't lessen the effect of our star's gravity.

Since the Sun is the most massive body in our solar system, its gravitational field is predominant. Other massive objects in the Solar system also have gravitational effects, but these are much weaker than that of the Sun.

Deep Chatterjee
LIGO Research Scientist, MIT Kavli Institute for Astrophysics and Space Research, Cambridge, Massachusetts

Q | WHEN CURIOSITY TAKES A SELFIE, WHERE IS THE SHAFT THAT HOLDS THE CAMERA? IT IS NEVER SEEN, LIKE THE CAMERA WAS PLACED ON A TRIPOD AND A TIMER SET. WAS IT EDITED OUT?

Bob Found
Indian Harbour, Nova Scotia

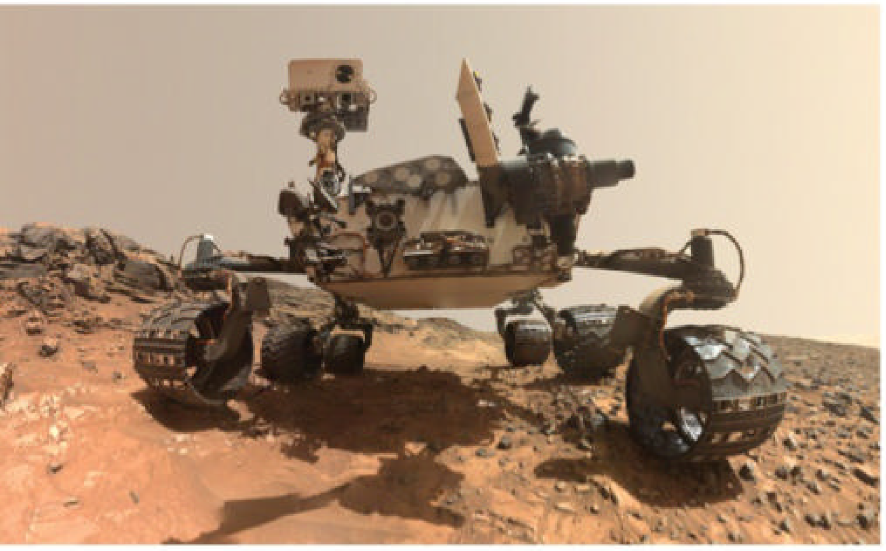
A | To take a selfie (like the one on pages 24–25 in our September 2022 issue), Curiosity uses the Mars Hand Lens Imager (MAHLI) camera on its multijointed robotic arm. The technique is roughly the same as when a human takes a selfie: Curiosity holds out its arm to snap the pic.

There are two reasons why the arm holding the camera is never seen. First, think about how you take a selfie with a phone: You do exactly as the rover does, holding the camera out with your arm extended. Your arm doesn't appear in the selfie because it is outside the view of the lens (below or behind it). Similarly, in many cases Curiosity's arm is outside the field of view of the lens.

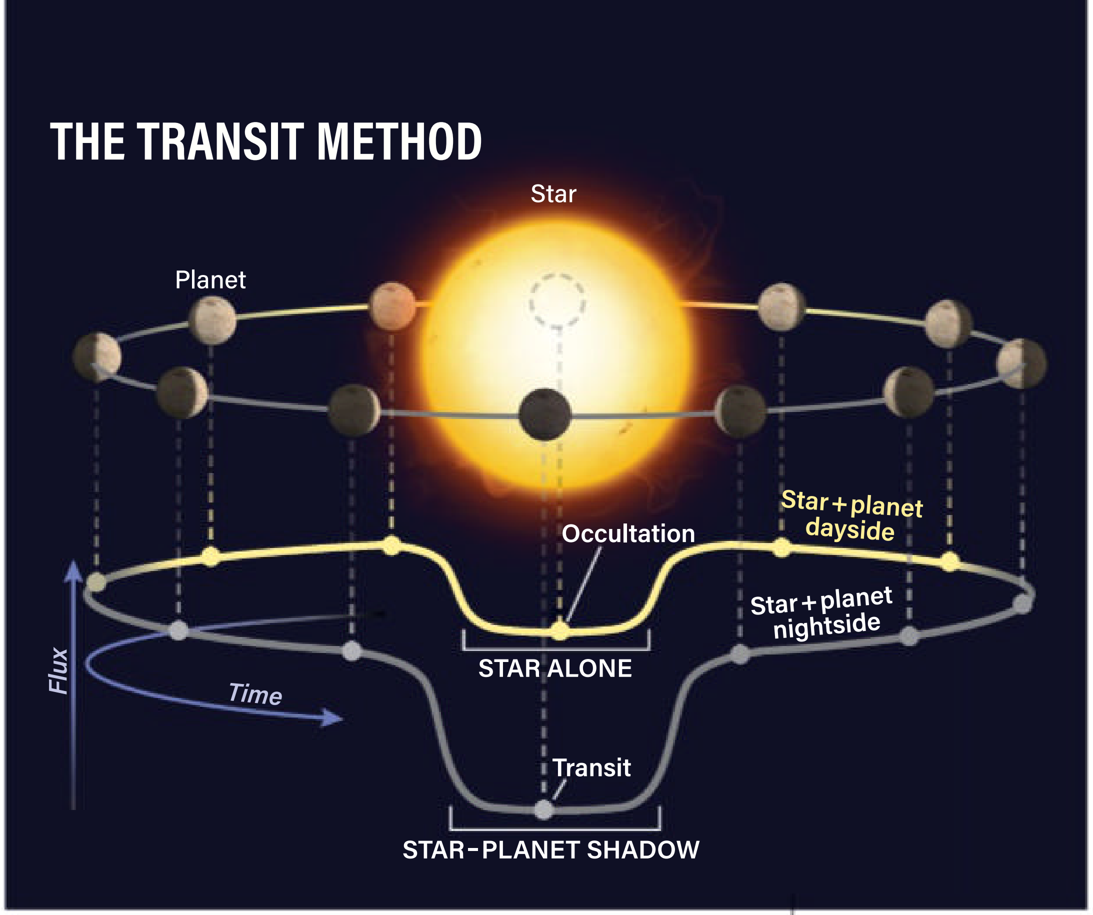
Admittedly, it's a bit more complicated for a rover to take a selfie than for a human, and this introduces the second reason why the arm is not visible. For us humans, selfies are a one-step process: Snap a pic and we're done. But Curiosity's camera can't capture the entire rover in a single shot, even from the end of its 7-foot-long (2.1 meters) arm. Instead, the rover must take dozens of photos to fit its entire body and background into the view. (This process can take an hour or more!)

To do so, the arm moves around the rover to snap images from many angles. In some of these raw shots, small portions of the arm may be visible due to the angle of the photo. However, the rover takes so many images that when NASA staff on Earth stitch them together into a final, single selfie, they can choose to use only portions of the images that do not include the arm. So yes, in cases where bits of the arm might appear in the image, it has been selectively edited out of the final result.

Alison Klesman
Senior Editor



Curiosity took this unique low-angle selfie shortly after drilling a rock called Buckskin. A portion of the rover's robotic arm is visible (of the three structures that stick up from the top of the rover, it's the light-colored shaft in the middle), but appears oddly cut off because the rest of the arm was not shown in the many images used to create this mosaic. NASA/JPL-CALTECH/MSSS



The transit method identifies planets by looking for dips in starlight as a planet passes between Earth and its host star. However, this only works when a star and planet happen to line up as we see them from Earth. Because stars and planets are oriented randomly in space, not all planets have orbits that carry them in front of their stars from our point of view. *ASTRONOMY*: ROEN KELLY

Q | SINCE THE TRANSIT METHOD RELIES ON DIRECT LINE OF SIGHT TO OUR PLANET, AND EXOPLANETS ORBIT WITH RANDOM ORIENTATIONS, HOW MANY EXOPLANETS ARE ESTIMATED TO BE UNCOUNTED USING THIS METHOD?

Edward Dean
Merritt Island, Florida

A | This is a really important correction we have to make when trying to calculate what fraction of stars have planets. The probability of a planet transiting its star from our point of view is proportional to the radius of the star (the bigger the star, the more area there is for the planet to potentially transit) divided by the distance between the star and its planet (planets that are farther from their stars are less likely to transit).

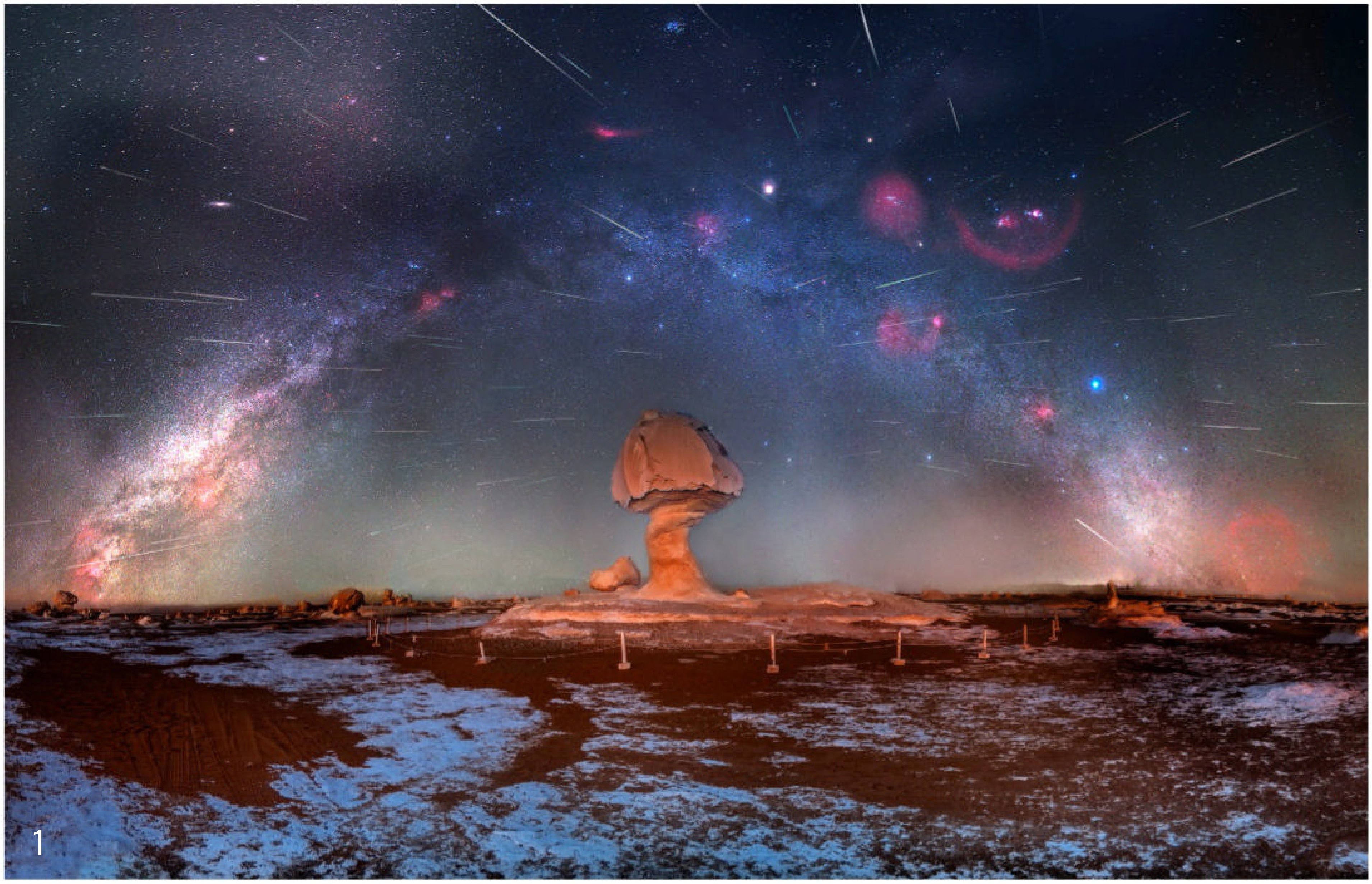
This probability ranges from about 1 in 10 for hot Jupiters — Jupiter-sized planets that orbit their stars in just a few days — to about 1 in 200 for Earth-sized planets that orbit their star with a period of 365 days. It's even smaller for more distant planets. Doing a quick calculation with the transiting planets we've discovered so far and examining their stellar hosts and their orbital distances, it looks like we've probably missed about 110,000 planets for the 4,000 that we've found!

Jessie Christiansen
NASA Exoplanet Archive Project Scientist, Caltech/Infrared Processing and Analysis Center, Pasadena, California

SEND US YOUR QUESTIONS

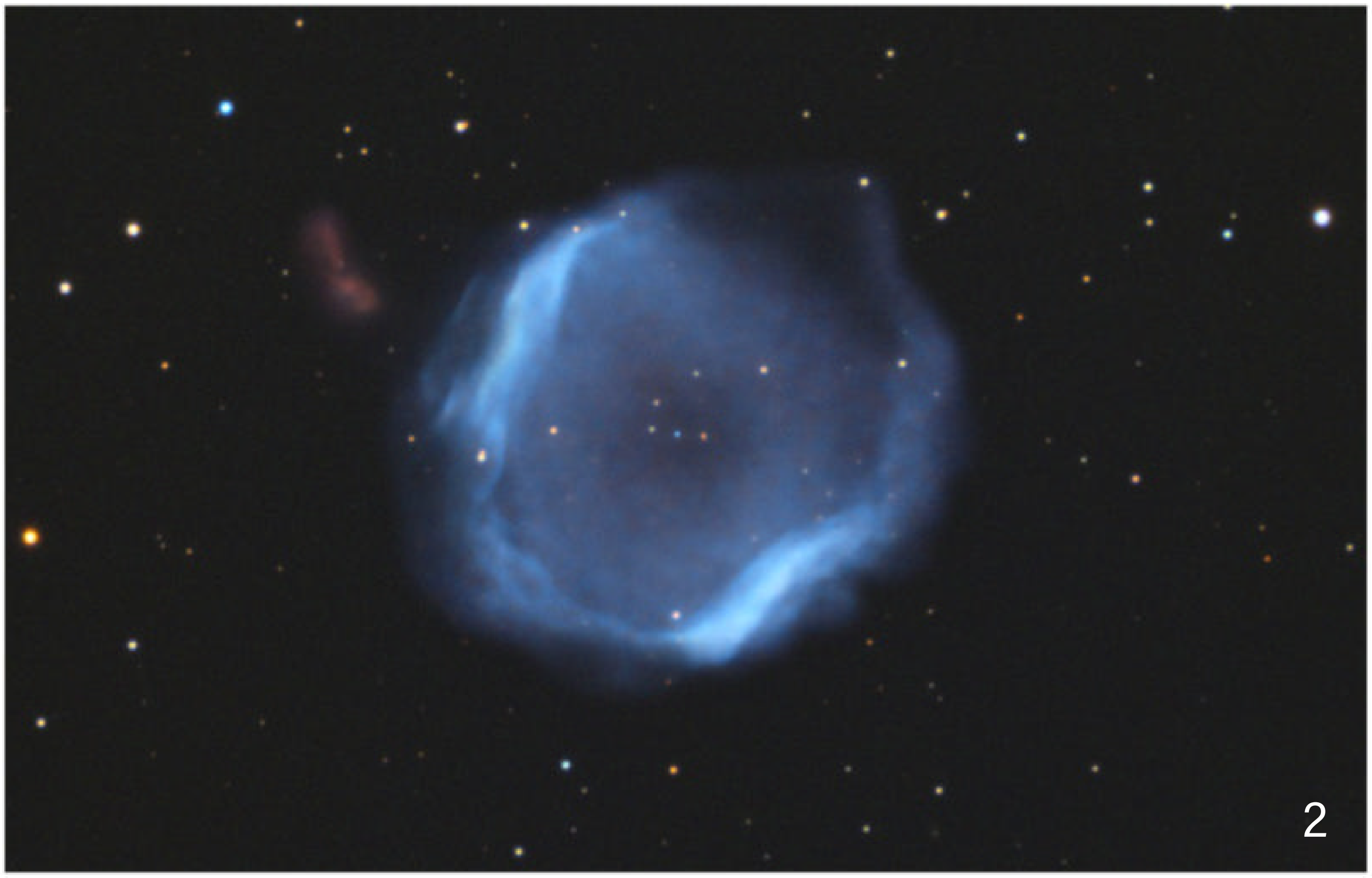
Send your astronomy questions via email to **askastro@astronomy.com**, or write to Ask Astro, P.O. Box 1612, Waukesha, WI 53187. Be sure to tell us your full name and where you live. Unfortunately, we cannot answer all questions submitted.

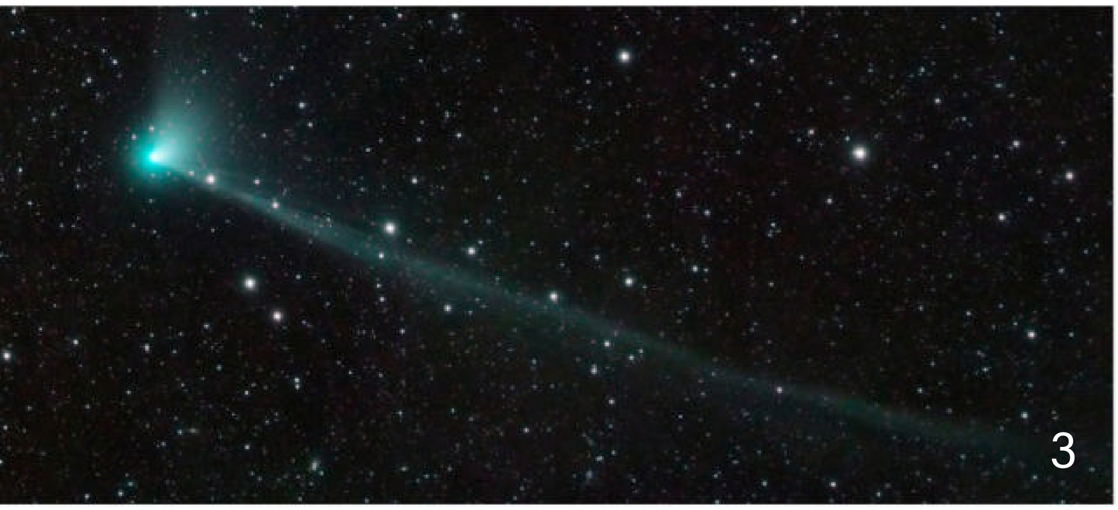
Cosmic portraits

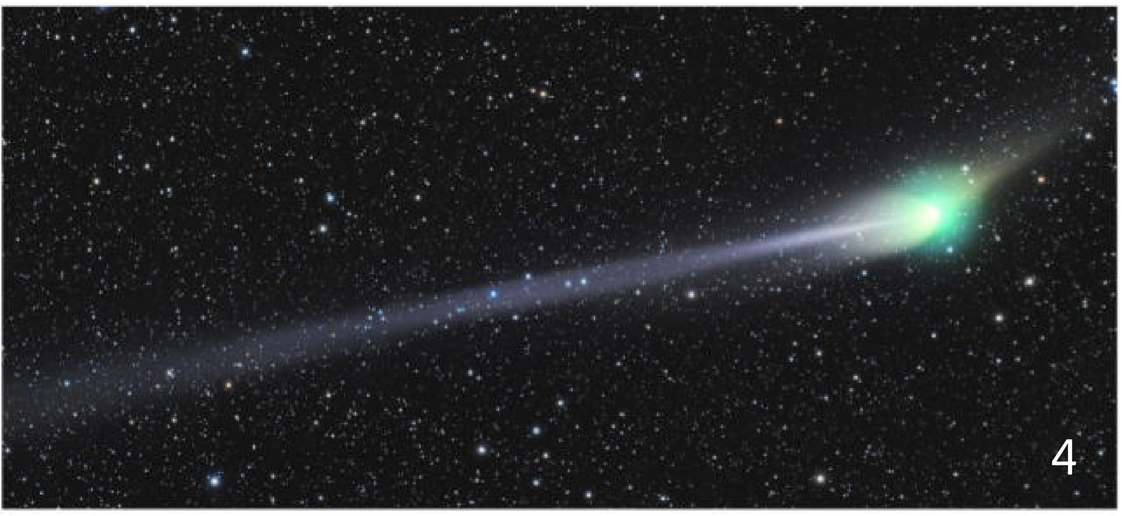


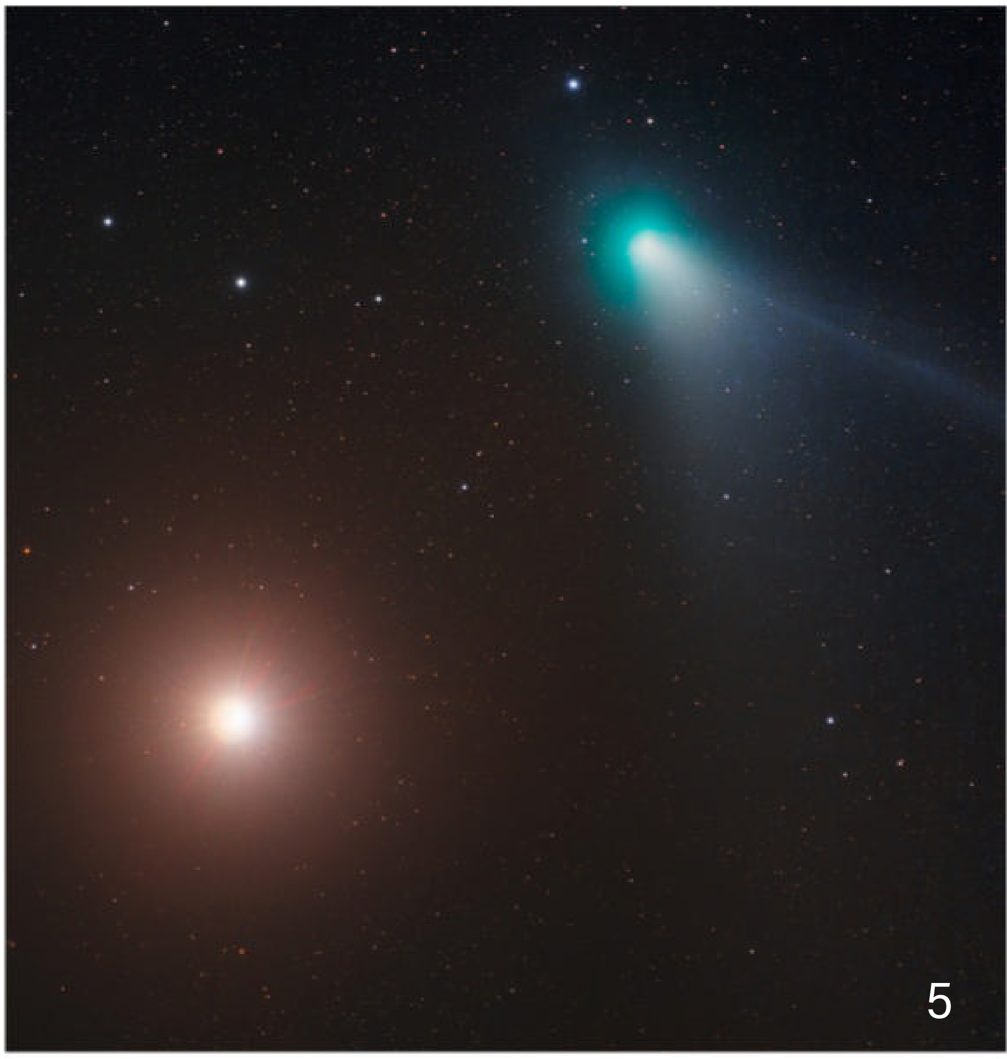
1. GALACTIC SOUP
Two rock formations — known as the Chicken and the Mushroom — in Egypt's White Desert lie under the Milky Way and the Geminid meteor shower in this mosaic. The sky panels consist of three-minute exposures at ISO 1000 with a zoom lens at 24mm and f/2.8. The foreground was captured just after sunset with 1/13-second exposures at ISO 200. **▪ *Osama Fathi***

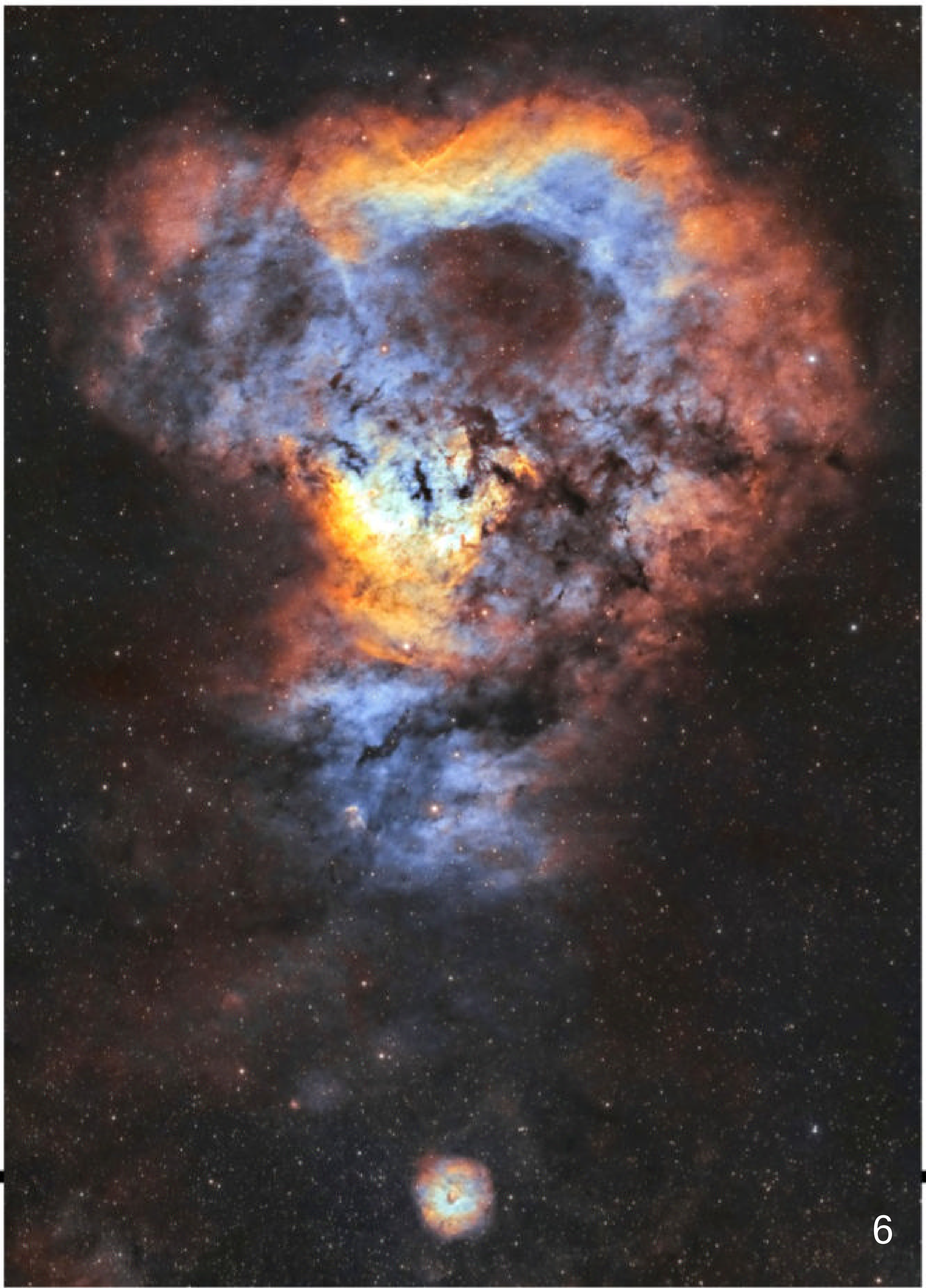
2. ONE OF A KIND
Jones 1 (also known as PK104–29.1) is a very faint planetary nebula in Pegasus discovered in 1941 by American astronomer Rebecca Jones. She joined Lick Observatory in 1927 straight out of undergrad and later worked alongside Harlow Shapley at the Harvard College Observatory for many years.
▪ *Douglas J. Struble*











3. WINTER TREAT
Comet C/2022 E3 (ZTF) gave comet watchers a gift at the end of 2022 and early 2023 — it reached perihelion on Jan. 12 and made its closest approach to Earth on Feb. 1, peaking at around magnitude 5. Its 3°-long tail stands out in this LRGB image from Dec. 24, 2022, representing 31 minutes of exposure with a 4.2-inch scope. ▪ ***José J. Chambó***

4. ZTF'S ANTITAIL
C/2022 E3 sprouted an antitail (at right) as it approached the Sun. Unlike the particles in a typical dust trail, those of an antitail are too large to be blown away by the Sun's radiation pressure. By a trick of perspective, they can sometimes appear to protrude from the front of a comet (to the right of the comet nucleus in this Jan. 24 image); in reality, though, the dust mostly trails the comet, remaining in the path of its orbit. This one-shot color image was taken over 7.13 hours of exposure with a 2-inch refractor. ▪ ***Drew Evans***

5. MARS FLYBY
Comet ZTF was beginning to fade as it made its closest visual approach to Mars on Feb. 11. This image of the encounter was taken with a 4.2-inch refractor and RGB exposures of 12 minutes each. ▪ ***Gerald Rhemann***

6. ANSWER: FORTY-TWO
The Cosmic Question Mark in Cepheus comprises two objects: the star-forming region NGC 7822 hovering over the dot of the Little Rosette Nebula (Sh 2–170). This image was taken in the Hubble palette and 17 hours on a 2-inch scope. ▪ ***Chuck Ayoub***

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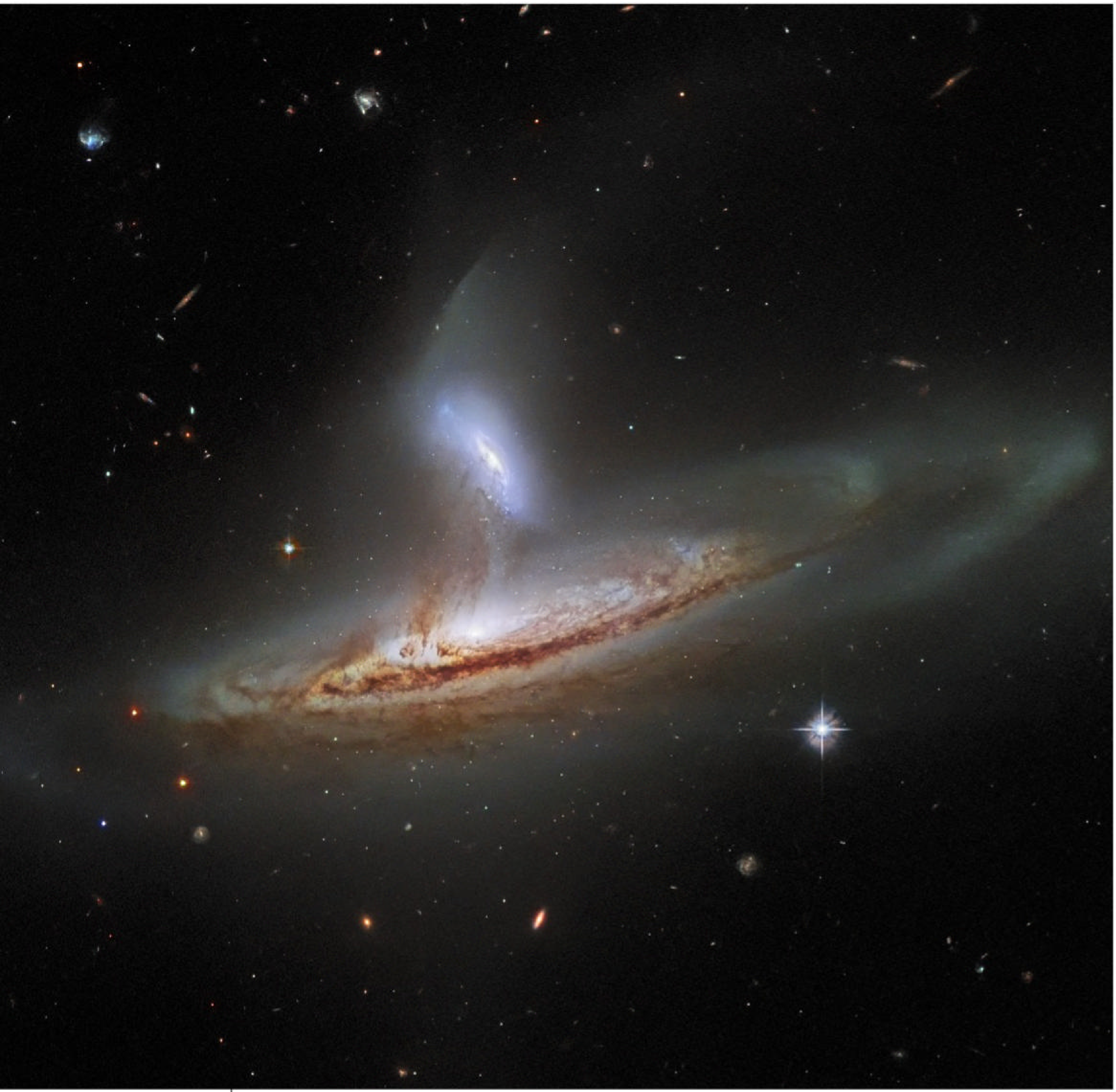

WELCOME TO MY WORLD

In a universe full of galaxies, you can't expect them all to get along. Although it might look like the large spiral galaxy NGC 169 is extending a helping hand toward its smaller companion, IC 1559, its intentions are decidedly hostile. The massive galaxy has started to strip gas, dust, and stars from its diminutive neighbor. This galactic tug of war won't end until NGC 169 fully cannibalizes IC 1559. Known collectively as Arp 282, the interacting pair lies 320 million light-years from Earth in southern Andromeda. Astronomers created this image combining observations from the Hubble Space Telescope, the Victor Blanco Telescope in Chile, and the Sloan Digital Sky Survey. ESA/HUBBLE & NASA, J. DALCANTON, DARK ENERGY SURVEY, DOE, FNAL/DECAM, CTIO/NOIRLAB/NSF/AURA, SDSS

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SOUTHERN SKY

BY MARTIN GEORGE

July 2023

Venus dazzles at dusk

If you tracked the motions of Venus and Mars during June, you noticed the distance between them shrinking steadily. But Venus' eastward motion relative to the background stars slackens during July, and the two planets never get closer than they do on the 1st. At the time of this so-called quasi-conjunction, these worlds appear 3.6° apart.

Venus stands out far more than its neighbor. The inner planet reaches greatest brilliancy July 7, when it shines at magnitude –4.7 — some 360 times brighter than Mars. The two spend the month low in the northwest after sunset against the backdrop of Leo the Lion, not far from that constellation's Sickle asterism.

July proves to be the last full month Venus remains visible in the evening sky. Its altitude decreases day by day as it prepares to pass between the Sun and Earth in mid-August. Yet its approach to both the Sun and Earth makes this a superb time to observe the planet through a telescope. Watch week to week as its disk grows and its crescent thins. During July, Venus' diameter swells from 33" to 53" while its phase dwindles from 32 percent lit to just 6 percent lit.

Mars continues its eastward motion against the star-studded background this month. On July 10, it passes 0.7° north of 1st-magnitude Regulus, Leo's brightest star. The magnitude 1.7 Red Planet glows slightly fainter than the star. A telescope reveals Mars' 4"-diameter disk, which appears featureless.

By mid-July, **Mercury** joins Venus and Mars low in the evening sky. But the best time to look for the innermost planet arrives during the month's final week. It passes 5° north (lower right) of Venus on the 26th and 0.1° south (upper left) of Regulus on the 29th. The best views of Mercury through a telescope also come late in the month. On the 31st, for example, the planet spans 6" and appears 63 percent lit.

Be sure to watch this area July 20 and 21, when a thin crescent Moon joins the scene. The gathering of Mercury, Venus, Mars, Regulus, and the Moon makes quite the spectacle — and presents a great opportunity for astro-imagers. For the most memorable photos, scout for a location that provides a pretty foreground.

Saturn becomes a fine sight later in the evening. It pokes above the eastern horizon by 10 P.M. local time in early July and by 8 P.M. at month's end. Magnitude 0.6 Saturn lies near the center of Aquarius the Water-bearer, a dim group whose brightest star glows at 3rd magnitude. Don't confuse the planet with the slightly fainter star Fomalhaut in neighboring Piscis Austrinus some 20° to its right.

You can expect spectacular telescopic views of Saturn once it climbs higher by late evening. Even a small instrument reveals the planet's golden disk, which measures 18" across the equator in mid-July, and the stunning ring system, which spans 42" and tilts 8° to our line of sight. A 10-centimeter or larger scope also shows 8th-magnitude Titan and three or four fainter satellites.

As Saturn climbs high in the north after midnight, **Jupiter** appears low in the east against the background stars of southern Aries the Ram. The giant planet rises by 3 A.M. local time in early July and nearly two hours earlier by month's end. Jupiter shines at magnitude –2.3, much brighter than any other planet or star once Venus sets.

If you wait until morning twilight commences, Jupiter appears high enough to deliver sharp views through a telescope, at least during those precious moments of steady seeing. The giant planet spans 38" in mid-July and displays a wealth of atmospheric detail along with four bright moons arrayed on either side.

The starry sky

People often ask me what astronomical sights have thrilled me the most during my decades of skywatching. The top spots would have to go to the many total solar eclipses I've seen, followed closely by some wonderful auroral displays and Saturn's occultation of the star 28 Sagittarii in 1989.

But there's one spectacular sight available to any observer every year, and not just on a single night. It's the view of the Milky Way on a dark moonless winter evening from the Southern Hemisphere. Seeing the central band of our galaxy stretching from horizon to horizon never grows old. And July marks the start of this viewing window.

The first instrument I used for observing was my father's 8x25 binoculars. They opened my eyes to many beautiful star clusters, though my favorites were the lovely open clusters M6 and M7 near the tail of Scorpius the Scorpion. They pass nearly overhead around 10 P.M. local time in mid-July. They look spectacular through 7x50 binoculars, as do many of the other clusters that dot the winter Milky Way.

Wonderful vistas await anyone who scans this region with binoculars or a telescope. Still, I never tire of the naked-eye view. M6, M7, and many other treats show up nicely without optical aid. But I want to highlight a feature formed by dust clouds in the Milky Way: the Emu. This huge structure stretches from Scorpius to Crux the Cross. The Emu's dark body resides in the Scorpion while his neck passes mainly through the constellation Norma the Square. It then skims past Alpha (α) and Beta (β) Centauri before reaching the Coal Sack in southeastern Crux, which forms the head. The Emu stands out well on any dark July evening.

STAR DOME

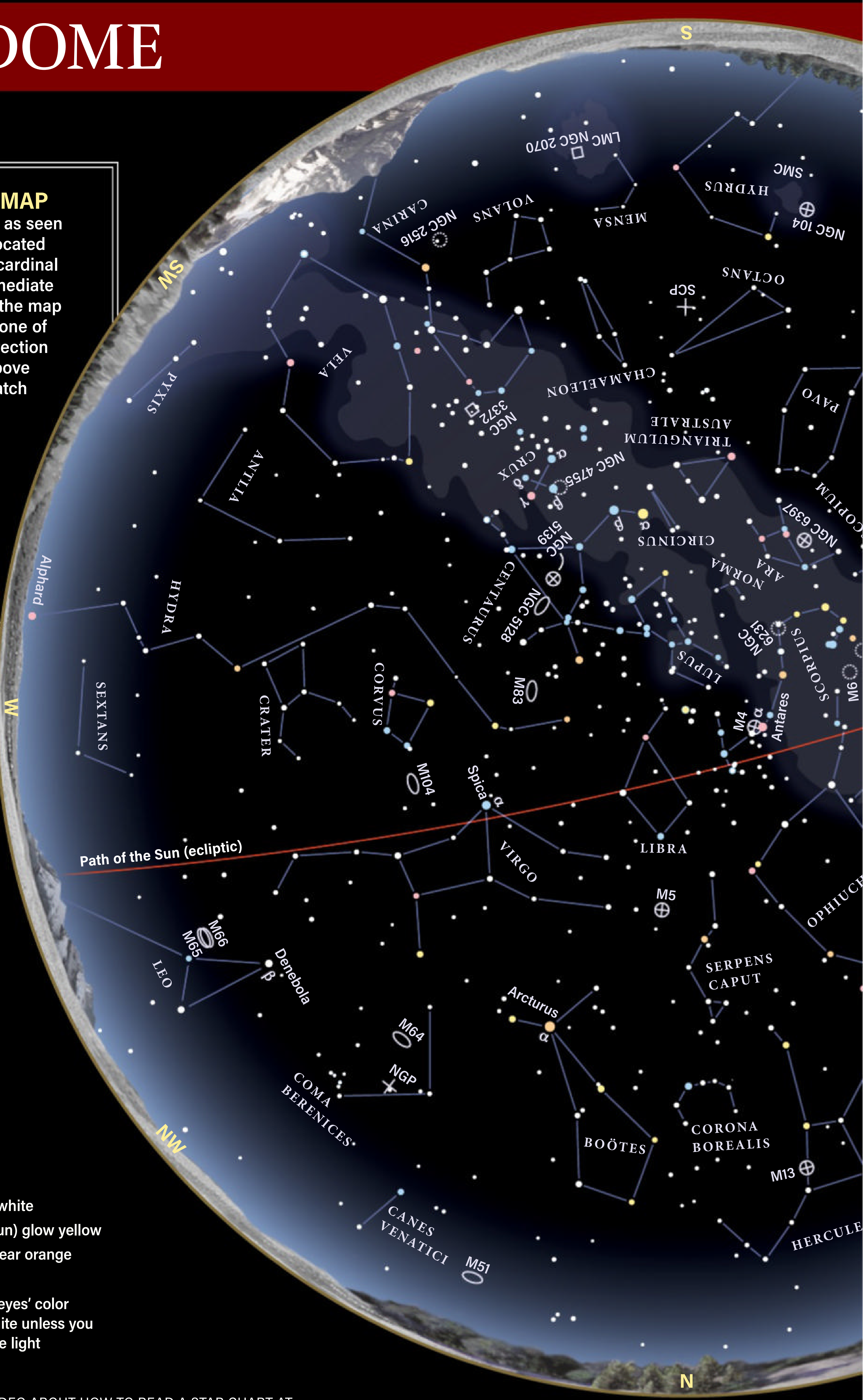
HOW TO USE THIS MAP

This map portrays the sky as seen near 30° south latitude. Located inside the border are the cardinal directions and their intermediate points. To find stars, hold the map overhead and orient it so one of the labels matches the direction you're facing. The stars above the map's horizon now match what's in the sky.

The all-sky map shows how the sky looks at:

9 P.M. July 1
8 P.M. July 15
7 P.M. July 31

Planets are shown at midmonth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CORVUS
M104
Spica
VIRGO
LIBRA
Path of the Sun (ecliptic)
M5
OPHIUC
SERPENS CAPUT
LEO
M65
M66
Denebola
Arcturus
M64
NGP
COMA BERENICES
BOÖTES
CORONA BOREALIS
M13
HERCULE
CANES VENATICI
M51

MAP SYMBOLS

- ◌ Open cluster
- ⊕ Globular cluster
- ☐ Diffuse nebula
- ⌖ Planetary nebula
- ⬭ Galaxy

STAR MAGNITUDES

- ● Sirius
- ● 0.0
- ● 1.0
- ● 2.0
- • 3.0
- • 4.0
- · 5.0

STAR COLORS

A star's color depends on its surface temperature.

- 🟦 The hottest stars shine blue
- ⬜ Slightly cooler stars appear white
- 🟨 Intermediate stars (like the Sun) glow yellow
- 🟧 Lower-temperature stars appear orange
- 🟥 The coolest stars glow red
- ⬜ Fainter stars can't excite our eyes' color receptors, so they appear white unless you use optical aid to gather more light

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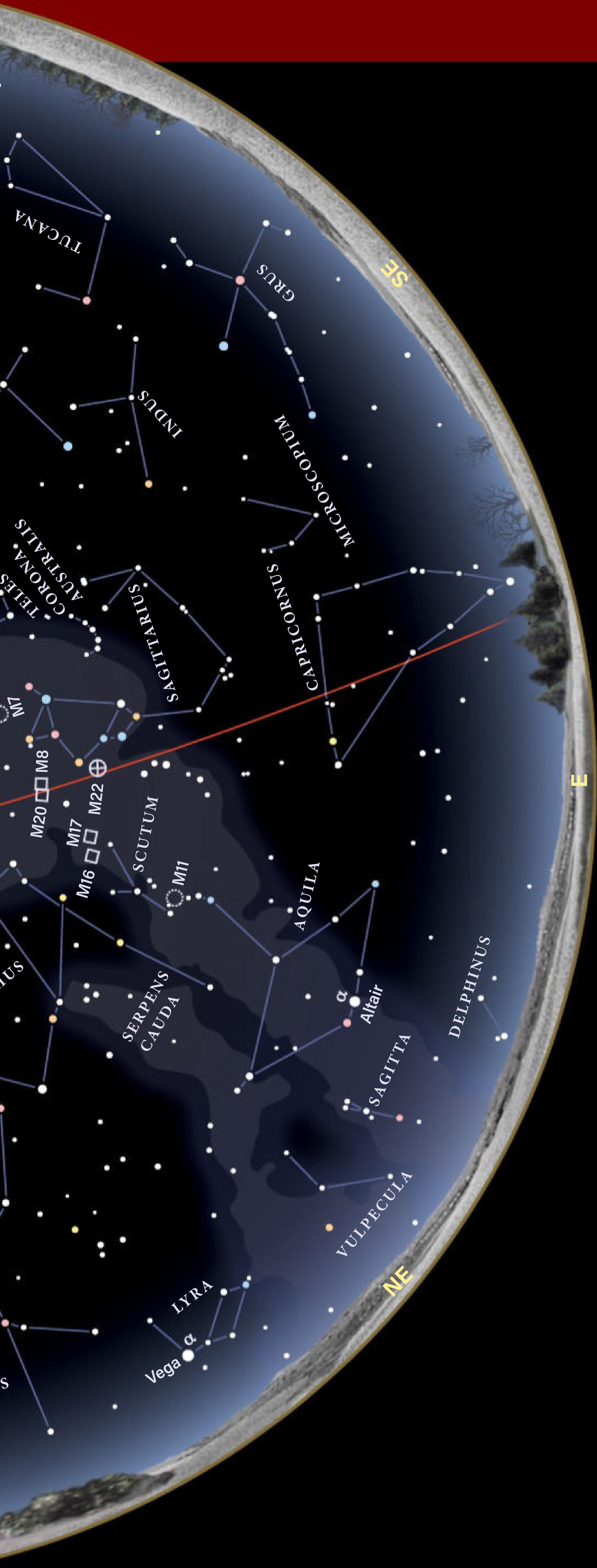
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JULY 2023

SUN.	MON.	TUES.	WED.	THURS.	FRI.	SAT.
						1
2	3	4	5	6	7	8
9	10	11	12	13	14	15
16	17	18	19	20	21	22
23	24	25	26	27	28	29
30	31					

ILLUSTRATIONS BY *ASTRONOMY*: ROEN KELLY

Note: Moon phases in the calendar vary in size due to the distance from Earth and are shown at 0h Universal Time.

CALENDAR OF EVENTS

1 Mercury is in superior conjunction, 5h UT
Neptune is stationary, 13h UT
3 Full Moon occurs at 11h39m UT
4 The Moon is at perigee (360,149 kilometers from Earth), 22h25m UT
6 Earth is at aphelion (152.1 million kilometers from the Sun), 20h UT
7 The Moon passes 3° south of Saturn, 3h UT
Venus is at greatest brilliancy (magnitude –4.7), 14h UT
Asteroid Eunomia is at opposition, 20h UT
8 The Moon passes 1.7° south of Neptune, 14h UT
10 Last Quarter Moon occurs at 1h48m UT
Mars passes 0.7° north of Regulus, 8h UT
11 The Moon passes 2° north of Jupiter, 21h UT
12 The Moon passes 2° north of Uranus, 18h UT
17 New Moon occurs at 18h32m UT
19 The Moon passes 4° north of Mercury, 9h UT
20 The Moon is at apogee (406,289 kilometers from Earth), 6h57m UT
The Moon passes 8° north of Venus, 9h UT
Venus is stationary, 23h UT
21 The Moon passes 3° north of Mars, 4h UT
22 Pluto is at opposition, 4h UT
25 First Quarter Moon occurs at 22h07m UT
26 Mercury passes 5° north of Venus, 13h UT
29 Mercury passes 0.1° south of Regulus, 1h UT
30 Southern Delta Aquariid meteor shower peaks

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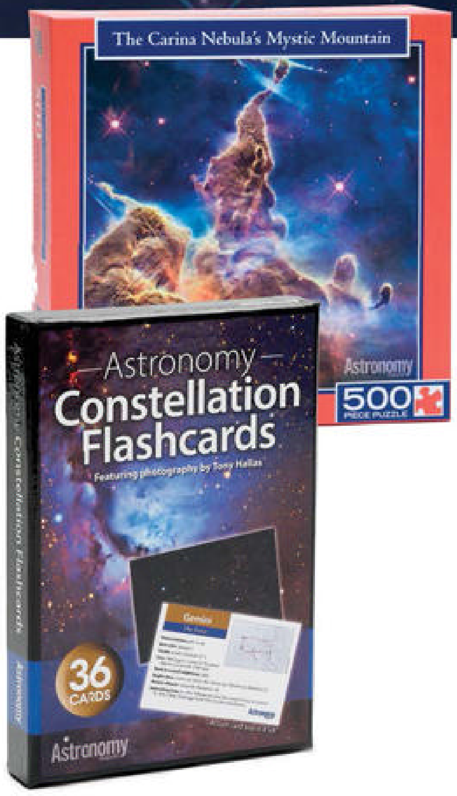
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The Milky Way from above
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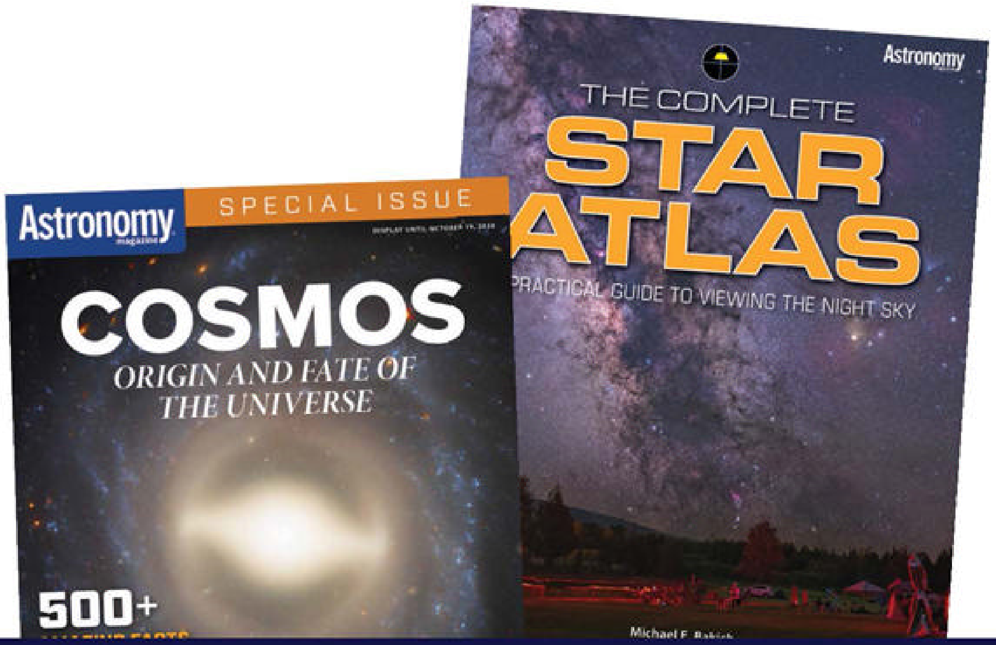
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